Issued January 13, 1913.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 263.

B. T. GALLOWAY, *Chief of Bureau.*

METHODS USED IN BREEDING ASPARAGUS FOR RUST RESISTANCE.

BY

J. B. NORTON,

Physiologist, Cotton and Truck Disease and Sugar-Plant Investigations.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., July 29, 1912.

Sir: I have the honor to transmit herewith a manuscript entitled "Methods Used in Breeding Asparagus for Rust Resistance," by Mr. J. B. Norton, Physiologist in the Office of Cotton and Truck Disease and Sugar-Plant Investigations, and to recommend its publication as Bulletin No. 263 of the Bureau series.

This paper deals with the methods developed in the selection, pollination, and breeding of asparagus at Concord, Mass. The work was done in connection with the rust-resistant asparagus breeding investigations being conducted at Concord by this Bureau in cooperation with the Massachusetts Agricultural Experiment Station.

The author desires to acknowledge the assistance of Mr. C. W. Prescott, of Concord, Mass., who, since the beginning of the work, has done everything possible to aid the breeding work. Mr. Frank Wheeler, of Concord, Mass., together with many other asparagus growers from various sections, has given active assistance in the work.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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METHODS USED IN BREEDING ASPARAGUS FOR RUST RESISTANCE.

INTRODUCTION.

History of asparagus rust.—Asparagus rust (*Puccinia asparagi* DC.), which has caused severe losses to asparagus growers in the United States during the past 16 years, is a native of Europe. Common asparagus (*Asparagus officinalis*) grows wild over the greater portion of Europe and parts of western Asia and northern Africa. This species, with several closely allied forms, is the normal host plant of the asparagus rust. There is nothing in the literature of the subject to indicate that the rust is in any way nearly as serious a pest in Europe as it has been in America. The comparative immunity of the crop in Europe is partly explained on the ground that the rust is held in check by its natural enemies and by climatic conditions. The gradual development of resistant varieties in Europe has had something to do with this apparent difference in severity of attack.

Occurrence of rust in America.—The definite occurrence of asparagus rust in America was unknown until 1896, when its discovery was recorded by Prof. B. D. Halsted,[1] of the New Jersey Agricultural Experiment Station. The same year brought reports of its occurrence on Long Island and in Massachusetts and Connecticut. It is very probable that the rust had been introduced in some way from Europe a year or so previously and had spread without being discovered. Since 1896 it has spread over practically the entire area of the United States where asparagus is grown. It became a factor in asparagus growing in the large fields of California in 1902.

Failure of spraying methods in the East.—In spite of the general interest and alarm felt by growers and station workers at the sudden appearance and rapid spread of this disease, satisfactory methods of rust control have not been developed for the eastern regions. Smith says:[2]

> In regard to methods of treatment for the control of the rust it may fairly be said that up to the time of the appearance of the disease in California nothing effective and satisfactory had been developed in other portions of the country previously affected.

[1] Halsted, B. D. Garden and Forest, vol. 9, 1896, p. 394.

[2] Smith, R. E. Bulletin 172, California Experiment Station, 1906, p. 1.

Many elaborate experiments with sprays have been carried out by different experiment stations, but for various reasons the growers as a class have failed to take up the practice of spraying. Here and there an isolated case exists where a farmer put in a spraying outfit at considerable cost and managed to check the rust so as to make his beds continue to yield paying crops. Most growers did not take up this work on account of its extra cost and trouble, either letting their old beds die out (Pl. I, fig. 1) or planting new fields (Pl. II) of such semi-resistant varieties as Argenteuil or Palmetto.

Previous attempts at breeding.—Some preliminary attempts have been made to start breeding work to develop resistant strains, but so far as the writer knows none of these attempts have been successful. Smith [1] makes the following statement:

A beginning has been made by the writer toward breeding desirable rustproof varieties by saving seed of such plants from various States, which is being carefully planted for such a purpose. Quite a collection is already on hand from promising sources. Seed has also been imported from Europe of a number of varieties grown there and plants have been obtained from all of these..

The preliminary work on spraying and variety testing brought out the fact that certain European varieties were more resistant to rust than the ordinary strains grown in the United States at the time the rust was introduced.

Hexamer [2] in his book on asparagus says:

All the cultivated varieties of asparagus are readily affected by the rust, although it has been found that some varieties, notably Palmetto, are less susceptible to its attacks than others.

Smith,[3] under a discussion of varieties, makes the following statement:

There is no question that some varieties of asparagus are more resistant to rust than others. This difference appears much more in new beds, planted after the rust outbreak started, than in those which existed at the time. So much is this true that in the East the rust problem seems well-nigh solved by the growing of Palmetto asparagus, yet in the first years of rust the difference in favor of this variety was slight and often not at all apparent. In 1900 Sirrine wrote that "The fields of Long Island have been watched every year since 1896, with the result that only slight, if any, differences in favor of the Palmetto were to be noticed, except that in some cases it did not succumb as early;" yet at present in the same fields the Palmetto alone remains and is being extensively planted. Mr. William Conover planted a field on his place in New Jersey with three rows of Palmetto, then three rows of Conover's Colossal, alternately, and after a few years the Palmetto was still green when the other variety was practically exterminated so that those rows had to be replanted with Palmetto. There is no doubt whatever that this variety is much less affected and less injured by rust in the long run, even though it does not always appear at first. The Argen-

[1] Smith, R. E. Asparagus and Asparagus Rust in California. Bulletin 165, California Agricultural Experiment Station, 1905, p. 95.

[2] Hexamer, F. M. Asparagus, Its Culture for Home Use and for Market, 1901, p. 140.

[3] Smith, R. E. Op. cit., p. 94.

FIG. 1.—AN ASPARAGUS FIELD ON CAPE COD, MASS., KILLED OUT BY SEVERE ATTACKS OF RUST AND NEVER REPLANTED.

FIG. 2.—FIELD SHOWING THE EFFECT OF RUST ON A NONRESISTANT VARIETY OF ASPARAGUS. ROW B24 (IN THE CENTER) WOULD HAVE BEEN AS VIGOROUS AS THE ROWS ON EITHER SIDE, BUT FOR RUST.

(From a photograph taken September, 1908, after the second season's growth.)

EFFECT OF RUST ON ASPARAGUS.

AN OLD ASPARAGUS FIELD AT CONCORD, MASS., KILLED OUT BY RUST. THE NEW FIELD OF READING GIANT ON THE LEFT WAS GROWN AS A BREEDING FIELD IN RUST-RESISTANT BREEDING WORK.

teuil (Bonvallet's Giant, French, and other trade names) is, if not identical with Palmetto, indistinguishable from it, and equally rust proof. Among all the American varieties no great difference exists, and they are in fact probably all selections from the old Conover's Colossal. * * * In a rusty field of any variety plants can be seen here and there which are greener, less affected, and more nearly rust proof than the average of the field.

Massachusetts Asparagus Growers' Association.—The publication in 1905 of Bulletin 165 of the California Agricultural Experiment Station by Prof. Ralph E. Smith, demonstrating the value of spraying and preventive measures in fighting rust, reawakened the interest of eastern growers. The general interest in plant breeding at this time, particularly in its application to the breeding of disease-resistant varieties of crops, suggested the possibility of its application to asparagus in fighting the rust. The fact that individual plants of a variety as well as different varieties as a whole varied in their rust resistance showed that the breeding proposition was not impossible. These facts led in 1906 to the organization of the Massachusetts Asparagus Growers' Association, with the object of securing by plant breeding a rust-resistant variety of asparagus. This association enlisted the cooperation of the Massachusetts Experiment Station and the United States Department of Agriculture. A cooperative plan of work was drawn up, under which, with some modification, the work has been carried out. The Department made collections of seed and plants from various sources and furnished the services of its experts in carrying out the breeding work. The Massachusetts station furnished the funds to run the work at Concord, Mass., where a branch experiment station was established on the farm of Mr. Charles W. Prescott. Beginning with the fall of 1908, the department has borne all of the expenses in connection with the breeding work, the funds formerly supplied by the Massachusetts station being needed for the proper development of the fertilizer and nutrition work on asparagus at the Concord station.

It must be understood at the outset that this work was intended to develop a rust-resistant strain of asparagus and not to discover remedial measures to help the nonimmune varieties already growing. Spraying treatments, etc., have been recommended by plant pathologists for years, but none have been generally adopted by the growers. The Massachusetts Asparagus Growers' Association started out with one idea, namely, the production of a strain that would be so immune to rust that the farmer would need to pay no attention to fighting the disease. This object has been kept constantly in view, and at present the prospect of success is so certain that no experiments with sprays will be undertaken. Nine out of ten growers in the East will not spray, anyway. Breeding work will produce better yielding types of commercially rust-immune asparagus, which will drive out the older fields as fast as it is possible to produce the stock.

PRELIMINARY WORK.

NATURE OF THE DISEASE.

In taking up breeding work for disease resistance, a knowledge of the life history of the organism causing the trouble is usually considered necessary. Previous work done in America on the life history of the asparagus-rust fungus by Halsted, Stone, Smith, and others has given us a basis of sufficient breadth to go ahead without further work. As a matter of fact, the methods of breeding used in this work have not depended on a knowledge of the life history of the rust fungus, except in a minor way. As yet we have found no constant differences in structure or physiology between the resistant and nonresistant plants.

Asparagus rust was described in 1805 by De Candolle as *Puccinia asparagi*. It belongs to the order Uredineæ, which comprises the group of fungi known as "rusts." These fungi are all parasitic on the higher plants, the most familiar examples being the common grain rusts. Asparagus rust differs from the grain rusts in being autœcious—that is, all stages of the rust occur on the asparagus plant, while the grain rusts are heterœcious, the spring stages occurring on a widely different host, wheat rust, for example, having its spring stage on barberry. The disease known to growers as asparagus rust is always the direct result of an infection from spores of *Puccinia asparagi* and, contrary to opinions held by many growers, is not caused by fertilizers, soil or weather conditions, insects, or anything else of this nature. However, once the disease is introduced, these other factors may influence its development and intensity.

The first activity shown in the spring by the rust occurs about the same time that the shoots of asparagus begin to appear above ground. At this time the resting spores of the fungus begin to germinate. From each cell of these spores there arises a short segmented filament, bearing four small sporidia. These sporidia are carried by air or water into contact with the young shoots just coming through the ground and on germinating send their mycelium through the epidermis of the shoot and establish themselves in the asparagus shoot. This mycelium after a growing period of less than a month, varying with weather conditions, starts to produce spores. These spores are located under the epidermis in groups commonly known as cluster cups or æcidia (Pl. III, fig. 2). These æcidia finally rupture the epidermis of the asparagus shoot and the light-orange spores are liberated. Accompanying the cluster-cup stage on asparagus are found honey-yellow spots of smaller size, known as spermogonia. These spermogonia produce small sporelike bodies that resemble the male spores of related orders, but which are now apparently functionless.

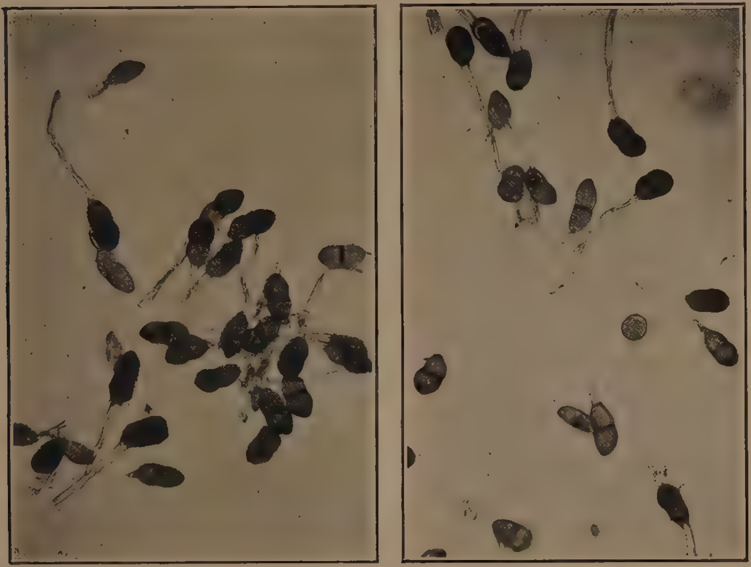


FIG. 1.—TELEUTOSPORES OF ASPARAGUS RUST. NEAR THE CENTER OF THE CUT ON THE RIGHT IS A UREDOSPORE. ×180.

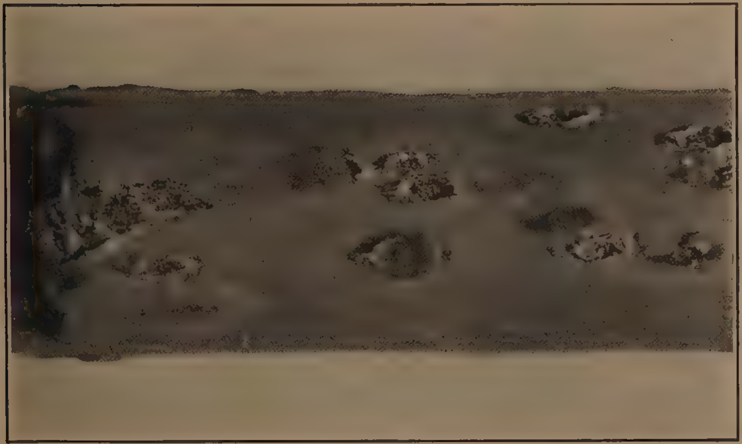


FIG. 2.—CLUSTER-CUP STAGE OF RUST ON AN ASPARAGUS STEM. ×3.

DIFFERENT STAGES OF PUCCINIA ASPARAGI.

ASPARAGUS BRANCH WITH SORI OF PUCCINIA ASPARAGI IN UREDO AND TELEUTO STAGES. ×5.

The spores from the cluster cups are usually rounded, orange yellow, and 1-celled. They are carried by air currents and lodge on the stems or cladodes of the asparagus plants. These spores germinate in the presence of moisture and produce a mycelium which grows into the asparagus plant through the stomata or breathing pores. These spring spores provide the infection which causes the summer rust or uredo stage. It is in this stage that the serious damage is done. The first signs of summer rust appear in about two or three weeks after the development of the cluster cups. The uredo spores appear in clusters of single-celled, red-brown spores which rupture the epidermis and are carried away by the air currents to reinfect other plants. At this stage the rust spreads rapidly. In warm weather accompanied by dew at night, the life cycle from uredo spore to uredo spore is often less than 12 days. This is shown by observations on seedling asparagus plants in the summer of 1909, when rust was repeatedly found on shoots that had been out of the ground less than 12 days. Beginning its attacks in the region of Concord about the latter part of June or first part of July, the uredo stage continues into October. Accompanying it and sometimes occurring alone is the teleuto stage (Pl. III, fig. 1), the fall stage, which goes through the winter to provide the spring infection. From the common name, fall rust, it might be assumed that this stage would be found only in the fall, but it has appeared regularly with the uredo stage at Concord during the summers since 1908 (Pl. IV). This is due to the fact that it appears under unfavorable circumstances, such as dry weather or prolonged periods of cool weather.

Asparagus rust has an active parasite in the fungus *Darluca filum*, a parasite of rusts in general, which is usually present in the rusted fields and is found attacking the rust in all its stages. During foggy or rainy periods in summer when the rust suffers most from Darluca, its attacks are reenforced by several saprophytic fungi, which often give a mildewed or molded appearance to shoots that have been injured by rust.

EFFECT OF THE DISEASE.

While the effect of asparagus rust is not seen directly in the marketed product, nevertheless it is quite injurious. The damage is due to the weakening of the plants by the attacks of the rust on the shoots during the summer after the cutting season is over. It is during the growing season that the plants store up food for the next spring, and if the shoots are injured or broken off the next season's food supply is accordingly diminished. When the rust attacks a plant no injury is apparent until the formation of the spore clusters ruptures the epidermis and allows excessive evaporation from the stems. The shoots

then wither and die. Attacks on the smaller branches and cladodes show a deadening effect shortly after the rust sori appear. On the whole the mechanical injury seems to be greater than any other. The attacks on young shoots in the late summer when the rust has become abundant are apt to be quite severe. This is due to the almost complete infection that takes place owing to the large number of uredospores blowing about while the growth is quite tender just as it comes through the soil. Spores are often developed from these infections before the shoot has had time to branch out and produce cladodes. These spore clusters or sori often are so numerous that they crack off the epidermis from large areas and the plants rapidly wither or stop growing.

COLLECTION OF VARIETIES.

The first work in starting breeding experiments was the accumulation of a collection of varieties from different sources. It was the aim to include in this variety test all possible sources of rust-resistant plants. In order to get the work started as soon as possible, eight rows of yearling roots were planted on the trial grounds at Concord, Mass., during May, 1906. These roots were contributed in lots of 100 by local members of the Asparagus Growers' Association, as shown in Table I. Row 9 was added the next season from roots obtained by Mr. Prescott.

TABLE I.—*Roots planted for breeding experiments in field A.*

Row.	Variety.	Source.
	Set May 5, 1906:	
1	New American (Geneva grown)	Anson Wheeler, Concord, Mass.
2	Do	Do.
3	Argenteuil (Concord grown)	F. E. Foss, Concord, Mass.
4	Do	Do.
6	Palmetto (Long Island grown)	Anson Wheeler, Concord, Mass.
7	New American (Concord grown)	Do.
8	(?) (Concord grown)	Wilfrid Wheeler, Concord, Mass.
	Set April 17, 1907:	
9	Palmetto (Long Island grown)	W. H. Reeve, Mattituck, Long Island.

During the fall and winter of 1906 a larger collection of seed and roots was obtained from most of the seedsmen in America and Europe and from interested growers in the asparagus region of the East. Mr. C. W. Prescott made a trip in the fall of 1906 through the asparagus regions of Long Island and New Jersey, securing seed from resistant stocks and fields. These lots of seed from all sources were germinated in flats in the greenhouses at Washington, D. C., in March, 1907; shipped to the field at Concord, Mass., in May, 1907; and planted in their permanent place in the trial rows. This treatment

was very severe and many plants failed to grow. Judging by the resistance and vigor of the plants in 1907, larger orders were placed that fall for seed of Late Argenteuil from Vilmorin-Andrieux & Co., of Paris, and for Reading Giant from Sutton & Sons, Reading, England. These lots of seed were grown in 1908 at Concord and were planted in 1909, 2½ acres of Argenteuil and practically the same of Reading Giant. No new strains have since been planted.

Table II shows the varieties planted in 1907 from the seed and roots obtained the previous fall and winter. It was the intention to have about 100 seedlings or about 10 roots from each lot.

TABLE II.—*Asparagus varieties planted in field B at the Concord Asparagus Experiment Station.*

Row.	Name of variety.	Source.
	FROM SEEDLINGS GROWN AT WASHINGTON.	
1	Dreer's Eclipse	Henry A. Dreer, Philadelphia, Pa.
2	Palmetto (Prescott 10)	Walter Van Fleet, Little Silver, N. J.
4	Hub	Joseph Breck & Sons, Boston, Mass.
6	Moore's Giant	Schlegel & Fottler, Boston, Mass.
8	do	W. W. Rawson & Co., Boston, Mass.
10	Palmetto	J. M. Mitchell, Mount Pleasant, S. C.
12	Mammoth Prolific	Moore & Simon, Philadelphia, Pa.
14	Donald's Elmira	Johnson & Stokes, Philadelphia, Pa.
16	Colossal	J. M. Thorburn & Co., New York, N. Y.
18	Rust Resistant	B. R. Tillman, Trenton, S. C.
20	Colossal	Jas. Barr & Sons, London, England.
22	Perfection	H. W. Buckbee, Rockport, Ill.
24	Seedling	R. P. Wakeman, Southport, Conn.
26	Late Argenteuil	Vilmorin-Andrieux & Co., Paris, France.
28	Vick's Mammoth	James Vick & Sons, Rochester, N. Y.
30	Sutton's Perfection	Sutton & Sons, Reading, England.
32	Reading Giant	Do.
34	Early Argenteuil	Vilmorin-Andrieux & Co., Paris, France.
36	Barr's Canadian	Barr & Sons, London, England.
38	Mammoth Emperor	James Carter & Co., London, England.
40	Barr's Mammoth	Jas. Barr & Sons, London, England.
42	Columbian Mammoth White	D. M. Ferry & Co., Detroit, Mich.
44	do	J. M. Thorburn & Co., New York, N. Y.
46	White German	Vilmorin-Andrieux & Co., Paris, France.
48	Erfurt Giant White	Ernest Benary, Erfurt, Germany.
50	Snow Cap Giant	Do.
52	Giant White Head	Heinemann, Erfurt, Germany.
54	Barr's New White	Jas. Barr & Sons, London, England.
56	Sutton's Giant French	Sutton & Sons, Reading, England.
58	Snow Head	Platz & Son, Erfurt, Germany.
60	Glory of Brunswick	Ernest Benary, Erfurt, Germany.
62	Palmetto	N. L. Willet Drug Co., Augusta, Ga.
64	Batavian	James Carter & Co., London, England.
66	Purple Dutch	Vilmorin-Andrieux & Co., Paris, France.
68	French Giant	Johnson & Stokes, Philadelphia, Pa.
70	Erfurt Giant	Heinemann, Erfurt, Germany.
72	Bonvallet's Giant	Vaughan's Seed Store, Chicago, Ill.
74	Early Argenteuil (Prescott 14)	Peter Henderson & Co., New York, N. Y.
76	Giant Argenteuil	Vilmorin-Andrieux & Co., Paris, France.
78	Palmetto	George Tait & Sons, Norfolk, Va.
80	Palmetto (Prescott 12)	Jas. J. H. Gregory & Sons, Boston, Mass.
82	Palmetto (Prescott 2)	W. H. Reeve, Mattituck, Long Island, N. Y.
84	Palmetto (Prescott 3)	Joseph Cooper, Mattituck, Long Island, N. Y.
86	Palmetto (Prescott 4)	A. L. Downs, Mattituck, Long Island, N. Y.
88	Palmetto (Prescott 5)	J. G. Downs, Mattituck, Long Island, N. Y.
90	Bonvallet (Prescott 13)	Vaughan's Seed Store, Chicago, Ill.
92	Bay State	A. D. Shamel, U. S. Dept. of Agriculture.
94	Palmetto (Prescott 1)	Joseph Cooper, Mattituck, Long Island, N. Y
96	Palmetto (Prescott 6)	Long Island Seed Co., Mattituck, N. Y.
98	Palmetto (Prescott 7)	Edwin Beeckman, Middletown, N. J.
100	Palmetto (Prescott 8)	W. B. Conover, Red Bank, N. J.
102	Palmetto (Prescott 9)	Dr. S. L. De Fabry, Little Silver, N. J.
104	Palmetto (Prescott 11)	Hiram Worthley, Concord, Mass.
114	Nutmeg State	A. D. Shamel, U. S. Dept. of Agriculture.

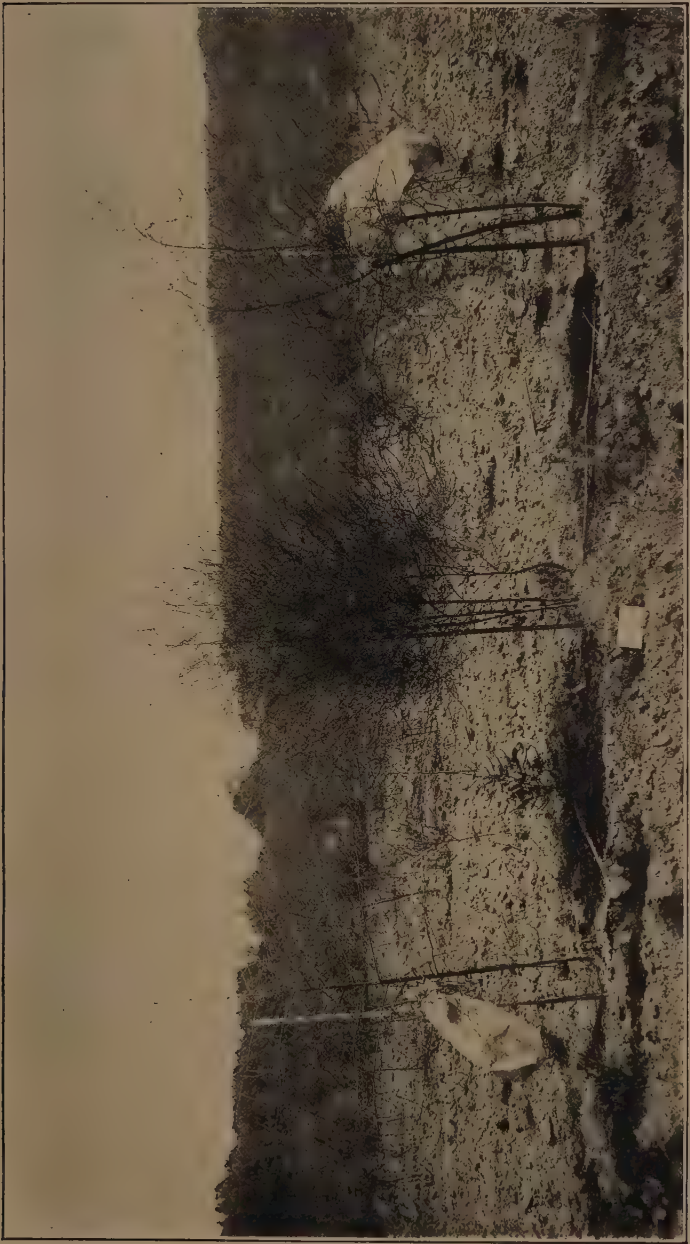
TABLE II.—*Asparagus varieties planted in field B at the Concord Asparagus Experiment Station*—Continued.

Row.	Name of variety.	Source.
	ROOTS OBTAINED FROM GROWERS AND SEEDSMEN.	
1	Dreer's Eclipse	Henry A. Dreer, Philadelphia, Pa.
4	Hub	Joseph Breck & Sons, Boston, Mass.
12	Mammoth Prolific	Moore & Simon, Philadelphia, Pa.
14	Donald's Elmira	Johnson & Stokes, Philadelphia, Pa.
15	.....do	Dr. B. T. Galloway, U. S. Dept. of Agriculture.
16	Colossal	J. M. Thorburn & Co., New York, N. Y.
20	.....do	Jas. Barr & Sons, London, England.
22	Perfection	H. W. Buckbee, Rockport, Ill.
26	Late Argenteuil	Vilmorin-Andrieux & Co., Paris, France.
28	Vick's Mammoth	James Vick & Sons, Rochester, N. Y.
30	Sutton's Perfection	Sutton & Sons, Reading, England.
32	Reading Giant	Do.
34	Early Argenteuil	Vilmorin-Andrieux & Co., Paris, France.
36	Barr's Canadian	Jas. Barr & Sons, London, England.
38	Mammoth Emperor	Jas. Carter & Co., London, England.
40	Barr's Mammoth	Jas. Barr & Sons, London, England.
41	.....do	Johnson & Stokes, Philadelphia, Pa.
42	Columbian Mammoth White	D. M. Ferry & Co., Detroit, Mich.
44	.....do	J. M. Thorburn & Co., New York, N. Y.
48	Erfurt Giant White	Ernest Benary, Erfurt, Germany.
49	Erfurt Giant	Heinemann, Erfurt, Germany.
50	Snow Cap Giant	Ernest Benary, Erfurt, Germany.
52	Giant White Head	Heinemann, Erfurt, Germany.
54	Barr's New White	Jas. Barr & Sons, London, England.
56	Sutton Giant French	Sutton & Sons, Reading, England.
58	Snow Head	Platz & Son, Erfurt, Germany.
60	Glory of Brunswick	Ernest Benary, Erfurt, Germany.
62	Palmetto	N. L. Willet Drug Co., Augusta, Ga.
64	Batavian	James Carter & Co., London, England.
66	Purple Dutch	Vilmorin-Andrieux & Co., Paris, France.
68	French Giant	Johnson & Stokes, Philadelphia, Pa.
72	Bonvallet's Giant	Vaughan's Seed Store, Chicago, Ill.
78	Palmetto	George Tait & Sons, Norfolk, Va.
107	.....do	T. S. Williams, Hattieville, S. C.
108	Giant Emperor	John Lewis Childs, Floral Park, N. Y.
109	(Unnamed)	South Carolina.

In addition to the above-mentioned lots, selections were begun in 1908 from about 5 acres of Imported Argenteuil and 2 acres of selected stock from the imported lot, both on the farm of Mr. Frank Wheeler, and from 3 acres of selected stock from Mr. Wheeler planted on the station grounds. This last field is being used for fertilizer and nutrition trials by the Massachusetts station.

VARIETAL UNIFORMITY.

Although many names are included in the collection of varieties, few distinguishing characters are to be found to separate the so-called varieties. A lot of seedlings would show nearly all the variations found in the whole trial field (Pl. V). One lot of Columbian Mammoth White that could have been the purest stock in the field in the character of whiteness showed no pure white plants in the whole trial row. To judge from the observations made on the varietal lots at Concord there are at present no pure strains of asparagus, the difference between the various lots being on a percentage basis. Thus, one lot may have more large stalks than another, hence it may



THREE PLANTS OF THE SAME VARIETY, B114, ARGENTEUIL, SHOWING WIDE DIFFERENCES IN TYPE OF MATURE GROWTH. IN SOME LOTS THE DIFFERENCES ARE EVEN MORE MARKED.

TYPES OF ASPARAGUS SHOOTS. NOS. 1 AND 3, GOOD; NO. 2, TOO LARGE AT BASE; NO. 4, ROUGH WITH PROJECTING SCALES; NO. 5, FROM SHORT SLOW-GROWING PLANT.

be called Giant; another lot may have more white plants and therefore may be given the name "White" or some similar term.

The observations at Concord showing lack of uniformity in varieties correspond to those of many experimenters and growers elsewhere who have written on the subject.

Ilott,[1] writing from the standpoint of an English grower, says:

> There are many so-called varieties, yet they differ but little. Messrs. Sutton & Sons of Reading have two—Perfection and Giant French—which are somewhat distinct. They are both excellent kinds, but whether they differ from others going by different names I do not know, for culture has a great deal to do with the appearance of asparagus, as of human beings. A variety which is sometimes well grown, and sometimes the reverse, varies much in appearance, thus favoring the idea of a difference of variety. Two other possibly distinct varieties are Argenteuil Early Giant and Argenteuil Late Giant, which latter probably keeps longer in the cutting season by furnishing shoots later than the first named. Conover's Colossal is another good kind, but not superior to those named above. Palmetto reached me a few years ago with a startling character. It is said to be both earlier and larger than any other, but planted side by side with all the kinds above mentioned I have not yet found it [to] display its alleged virtues. It came from America, and it is possible that it went over there first from Europe, probably from England, for I find it about as good as many others. As to size, it is smaller than Sutton's Giant French. The only other variety which I am going to mention is one which was sent out by Messrs. Bunyard. They named it Harwood's Early, and it is noteworthy as being alleged to be the earliest to become fit for the markets. It certainly has in my experience for three years in succession started before the other kinds. There is, however, as I consider, far more importance in soils, sites, and general cultivation than in difference of variety, and whereas the cultivation differs materially, the varieties do not, in any great measure, differ from one another.

H. W. Ridgway,[2] of Swedesboro, N. J., one of the best growers in the East, in a recent discussion of asparagus growing, says:

> Variety is the principal thing, but in making our selection of variety let us not put too much dependence on the name. It may be misleading, owing to the fact that many growers are not acquainted with the varieties and accept the name given them without questioning its authenticity. There is only one species and several varieties; one-half of the names that we hear are not varieties. The grass so named has been caused by methods of cultivation, highly-manured land, and climatic conditions, and differ from each other only by a single characteristic which will rapidly disappear when grown under climatic and soil conditions different from that in which they originated.

Smith in his work in California found no uniform varieties and many names applied to strains that differed from each other in no appreciable way. The same opinion as to varietal differences is held by most growers who have been interviewed.

One thing is apparent in looking over tests of varieties, namely, that no real pedigree breeding has been done. A search through

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[1] Ilott, Charles. The Book of Asparagus, 1901, p. 2.

[2] Ridgway, H. W. Extract from Thirty-sixth Annual Report, New Jersey State Board of Agriculture, 1909, pp. 114–115.

available literature reveals no pedigree work nor even plans for any. The variability of the best imported strains seems to settle the matter (Pl. VI), at least as far as Europe is concerned. The results from one generation of pedigree breeding at Concord show that uniformity can be obtained in many characters by proper selection of parent types, yet it is highly probable that little real advance in asparagus varieties has been made since the time of the Roman gardener who grew stalks of such size that three weighed over a pound.

A quotation from Hexamer[1] shows the best method recommended by authors in giving advice as to seed growing. This method is practically the same as that recommended by most European writers and is that followed by some of the best growers in this country.

In order to insure the production of the very best asparagus seed a sufficient number of pistillate or seed-bearing plants, which produce the strongest and best spears, should be selected and marked so that they may be distinguished the following spring when the shoots appear. These clumps should be close together and near some staminate or male plants which have to be marked likewise, as without their presence fertile seed can not be produced. The number of the male to the female plants should be about one to four or five. The following spring all the sprouts of the selected male plants are allowed to grow without cutting. On each hill of the female plants the two strongest and earliest stalks are allowed to grow, cutting the later appearing spears with the others for market or home use. Thus these early stalks of both male and female plants bloom together before any other stalks, and the blooms on the female plants will be fertilized with the pollen of the selected male plants. This last is of prime importance, for on proper fertilization depends the purity of the seed as well as the vigor of the resultant plant. Not all seed of even a good plant properly fertilized should be used for reproduction, as of the seeds gathered from any plant some will be better than others. Only the largest, plumpest, and best-matured seeds should be used, for by saving these the most nearly typical plants of the sort will be most certainly produced. The selection of the best seed from typical plants is as essential to success as are good soil, thorough cultivation, and heavy manuring.

VALUE OF UNIFORMITY.

The uniform distribution of good asparagus over the field is a matter that has received some attention from growers. The yield and type of the individual plants in most varieties differ widely, and it is probable that less than half of the plants pay a profit. This difference in yield is illustrated graphically in figure 1. A separate record was kept of the cut of each hill in row A1, New American, Geneva-grown stock, in its fifth season in permanent place in the bed. The diameter of each stalk was measured, this method being considered more reliable than to take the weight. This diagram shows that 37 of the hills cut above the average and that unquestionably many plants in the row were not paying for ground rent, fertilizer, and labor.

[1] Hexamer, F. M. Asparagus: Its Culture for Home Use and for Market, 1901, p. 27.

This row represents an "average" lot of plants. Some beds in Concord and vicinity show a higher average efficiency, but many are lower.

INTRODUCTION OF UNCULTIVATED SPECIES.

In connection with the introduction of asparagus varieties for the rust-resistant work, several wild species have been brought in by the Office of Foreign Seed and Plant Introduction from different regions for distribution. *Asparagus* (*Asparagopsis*) *virgatus* from South Africa was tested at Concord in 1908 and proved to be entirely free from rust. The following winter all the plants were killed by cold. Later trials at Washington have shown that this species is quite tender. Mr. George W. Oliver, of this Bureau, has tried to cross this species with *A. officinalis*, but without success. *A. officinalis pseudoscaber* was tested in 1911 at Concord but proved quite susceptible to rust. So far the attempted crosses between this variety and the parent form have failed to give hybrid plants. *A. davuricus*, a related form from China, was pollinated in 1911 with *A. officinalis* pollen and has given seedlings that show hybrid characters. *A. davu-*

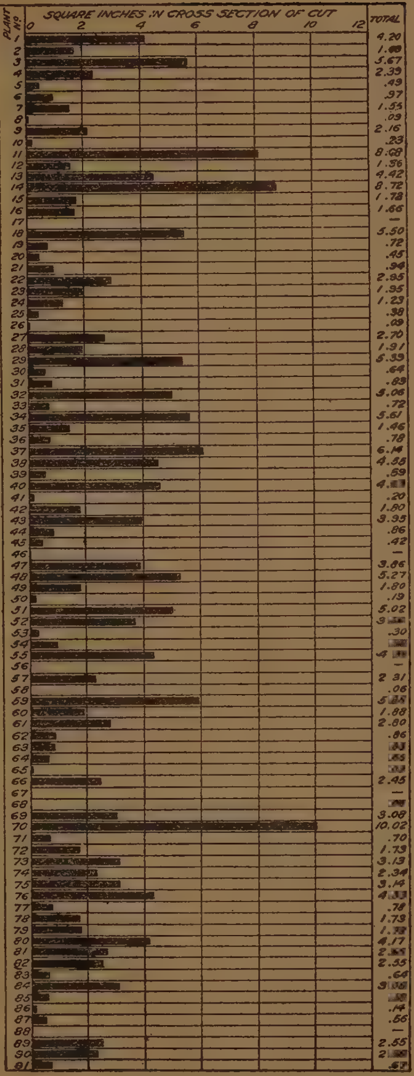

FIG. 1.—Diagram showing the comparative yields of individual plants of row A1, season of 1910. The yield is shown in the sum of the squares of the diameters of the stalks cut from each hill.

ricus has not been tested for rust resistance. Its size and hardiness indicate that valuable forms might possibly come from hybrids between it and *A. officinalis*.

A collection of forms of asparagus from all over the Old World is being made, and as these plants come into bloom hybrids will be made with *Asparagus officinalis* wherever possible. Of course, many species are not closely related to the cultivated forms and will not give fertile hybrids. These forms will be grown to determine their possible ornamental value and to aid in a systematic study of the group.

SELECTION.

PRELIMINARY METHODS.

The first work of selecting rust-resistant plants was begun in the fall of 1908. At that time no definite information was obtainable in regard to rust-resistant plants. It was not definitely known that the resistance was due to a character inherent in the plant, or to some local condition that rendered the plant immune for that environment or season only. The relative value of a resistant plant in a resistant lot as compared to an equally resistant plant in a lot or strain that averaged more rusty was unknown.

Several hundred marking stakes were made from ordinary lath sharpened at one end. These lath can be readily seen at some distance in an ordinary asparagus field. The experimental fields were gone over and every plant showing exceptional resistance was marked. In the fall of 1908 the variety test plats in fields A and B, comprising about 2 acres of different strains, were gone over in this way. Three acres of Argenteuil, Mr. Frank Wheeler's select stock, on the station grounds and several acres on the farm of Mr. Wheeler were also included. This work was repeated in 1909 and again in 1910. In 1909, selections were first made from the new plantings of Reading Giant and Late Argenteuil set out in permanent beds that spring. These beds have been included in the selection areas since that time. Besides some new untested plants, the selections of 1910 included only those plants of past years that had been progeny tested and proved of value as breeders. In 1909 many cross-pollinations were made between the select plants of 1908. Eleven hundred of these seedlings grown in the greenhouse were planted on the station grounds in 1910 in four rows with hills 1 foot apart in the row. These pedigree lots were included in the selections of 1910 and 1911.

GREENHOUSE INFECTION.

When the plans for rust-resistant breeding work were laid out in the fall of 1908 it was intended that the experimental infection of seedling plants to determine their relative resistance would be carried on during the winter months in the greenhouses at Washington. In this way it would be possible to gain a season. For various reasons this plan proved impracticable. The rust is not readily transferable in the greenhouses, owing to the lack of dew. The fact that uredospores do not germinate unless properly ripened on the host is another factor. During the fall of 1908 and again in 1909 the rusty plants brought into the greenhouses died back, so that the rust infection was lost and the new shoots coming up had no rust on them. The feeling that the different conditions of moisture, heat, etc., existing in the greenhouse might cause an entirely different rust relation as compared to that of the field has led to the dropping of this part of the plan. The work is now so far along that the greenhouse infection work is unnecessary.

JUDGING RUST RESISTANCE.

In the work at Concord the preliminary selection of breeding stock was begun in the fall of 1908 on fields A and B, planted in 1906 and 1907. The plants were marked for rust resistance on a scale of 0 to 10, the zero mark being used for a plant practically nonresistant and at the time of selection showing no green whatever as a result of a strong rust infection, 10 being the mark for a plant having no rust. The intermediate grades were assigned to plants showing intermediate degrees of infection according to the personal judgment of the observer. Experience in judging amounts of rust is required. The first season's marks are not as accurate as those of later years, because the plant as a whole rather than the rustiest stalk was then considered. The experience of later years has shown that the rustiest stalk in the hill is the best index, as many of the earlier stalks do not rust badly. They become hardened and seem more immune than the shoots that come up when the rust has become prevalent and is giving a strong infection. In making breeding-stock selections in the future no plants will be saved that do not show practical immunity to the rust.

In connection with the selection work the question was raised by visiting experimentalists as to the reliability of the methods used in marking resistant plants. In order to test the value of the marks assigned, row A1 was scored on two successive days, the second marking beginning at the other end of the row from the first so as to eliminate the factor of memory as far as possible. The result of the score is shown in a correlation table (Table III).

TABLE III.—*Correlation between two independent gradings of row A1 for rust resistance, September, 1911, to test reliability of values assigned by observer.*

[Coefficient of correlation 0.925±0.013.]

Grades.	First marking (grades).										Frequency.	Departure from mean.
	1	2	3	4	5	6	7	8	9	10		
Second marking:												
1	4										4	−5
2		3									3	−4
3			4	3							7	−3
4				3	2	1					6	−2
5				1	5	1	7				14	−1
6					2	3	2	2			9	0
7							3	7			10	+1
8							2	15	8		25	+2
9									2		2	+3
10										1	1	+4
Frequency	4	3	4	7	9	5	14	24	10	1	81	
Departure from mean	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	......	

The greatest deviations are in the middle grades, but as these plants are not valuable for breeding parents the high correlation between the grading in the two sets of observations from a practical standpoint is higher yet. This method of checking up the value of grades assigned in selection work where the personal equation largely enters should be followed more extensively than it is at present. The ability to accurately judge differences of minor degree adds greatly to the value of the work.

RECORD OF SELECT PLANTS.

In making selections some permanent record is necessary. Permanent stakes in the field are not desirable, on account of the spring cultivation with a disk harrow. In our experimental plats the plants are placed at definite distances apart and a record made of a select plant, giving its row number and plant number to enable it to be relocated in the spring. Four-foot lath make cheap and convenient stakes which can be seen for some distance in the field. When plants in a cutting bed are to be left for seed, it is necessary to mark them so the cutters will let them alone.

PROTECTION OF SELECT PLANTS FROM FROST.

On account of late frosts occurring after the selected plants are up a foot or so, it is sometimes necessary to cover them over night. Manila paper bags are very good for this purpose. When the shoots were covered with moist earth at times when the temperature went low enough to make ice one-fourth of an inch thick, the stalks froze and when the sun came out they thawed out rapidly enough to be killed. At the same time the shoots under the manila bags escaped injury. A peculiar frost phenomenon was observed in June, 1910, when a light

frost occurred in the lowest portions of one of the breeding fields. Glassine paper bags, which are used to cover flowering branches on female plants in breeding work, instead of protecting the flowers from frost actually increased the injury, so that the flower buds dropped off under the bags, while the unprotected buds outside remained uninjured.

RUST INFECTION TO SECURE SELECT RESISTANT PLANTS.

During the past three seasons there has been an abundance of rust during July, August, and September on the experimental grounds at Concord. This abundant attack of rust is necessary to obtain selections of any practical value. The attack of rust should deaden the tops of practically 95 per cent of the young seedlings from standard Argenteuil stock in the seed bed, or in its ravages in a commercial field of good Argenteuil make it possible for a beginner to pick out less than 10 resistant plants per acre as being plainly superior in rust resistance to the other five or six thousand.

So far in this work no asparagus plants have been found that will not rust to some extent. There is a wide difference in susceptibility in different varieties. The old American sorts represented in Concord by Moore's crossbred are practically nonimmune, while Argenteuil and other related European varieties are highly immune, so much so that they are not troubled by rust unless a new bed planted near by is not being cut in the spring.

There is no question that the spread of the rust from one field to another depends on the direction and intensity of air currents. On the experimental field at Concord the prevailing winds are from the northwest. This fact, combined with the circumstance that the dew dries up last on the northwest side of the plant, makes the heaviest attacks of rust on the shady side. On account of the direction of the prevailing wind at Concord, it is highly advisable to have any infection area on the north or west of the seedling bed to be infected. Once a field has had a good infection of rust and the resistant plants marked, it is not necessary to provide rust in future seasons, as the select plants can be tested by growing pedigree seedlings.

In fact, it is not necessary to test the individual resistance of a plant in order to determine its value as a breeding parent. All that is necessary is to test a small lot of its seedlings.

CAUSES OF RESISTANCE.

Æcidial stage on resistant plants.—An interesting feature of the rust-resistant breeding work developed in the spring of 1909, when the cluster-cup stage of the rust appeared. The plants that had been selected as rust resistant in 1908 were allowed to grow without being

cut. In addition to these selected plants several nonresistant plants were allowed to grow up to be used in crossing tests to determine the dominance of the resistant character. No uniform differences in the æcidial infection could be noticed, many of the most resistant plants having a better infection than the rusty plants. This development caused some doubt as to the nature of resistance and made it seem possible that the immunity of the year before might be due to some temporary factor. Later in the season when the summer stages of the rust appeared this doubt was dissipated, as the resistance again appeared in the select plants of the year before in about the same degree as in the previous season.

Relation of structure to resistance.—The fact that sporidia from germinating teleutospores can infect through the epidermis without necessarily entering through the stomatal openings gives an explanation for the phenomenon just noted and sheds a possible light on the cause of rust resistance in asparagus.

It is a well-known fact that in the heterœcious rusts the æcidial stages occur on plants widely different in general character from their hosts when in the uredo or teleuto stages. Thus there is reasonable ground on which to oppose the theory that rust resistance is due to structural differences simply because the æcidial stage appears on resistant plants as freely as on nonresistant ones. However, the theory that in asparagus resistance has a morphological cause is reenforced by several other points. While little work has been done on this problem in asparagus, the evidence tends to show that resistant plants have smaller stomata than the nonresistant ones. It may be, of course, that the size of guard cells is not closely correlated with the actual size of the opening through which the mycelium must pass, but it gives a suggestive point of attack in solving the problem. When the rust develops in a field in summer, the shoots that came up first and have fully matured and hardened develop a lighter attack of rust than the shoots which appear during the height of the rust epidemic. Once the rust gets started in the plant it goes ahead in its development equally well in resistant and rusted plants, no difference being discernible in the type or vigor of the individual sori on plants of different degrees of resistance.

Ward,[1] in his studies of rust resistance in the genus Bromus, comes to the conclusion that resistance is not due to structural causes. He says: [2]

> We are hence driven to conclude that the factors which govern predisposition on the one hand and immunity on the other are similar to those which govern fertility and sterility of stigmas to pollen * * *.

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[1] Ward, H. M. On the Relations between Host and Parasite in the Bromes and Their Brown Rust, Puccinia Dispersa (Erikss.). Annals of Botany, vol. 16, 1902, pp. 233–315.

[2] Ward, H. M. Op cit., p. 314.

In a later study of rust resistance Ward[1] says tha this researches "clearly led to the conclusion that the matter has nothing to do with anatomy, but depends entirely upon physiological reactions of the protoplasm of the fungus and of the cells of the host."

Until sufficient evidence has been accumulated on the correlations between structure and rust resistance in asparagus the writer does not care to claim definitely that the size of the stomata is related to the phenomenon of resistance to the attacks of the uredo stage of the asparagus rust. The presence of the æcidial stage on the asparagus plant gives a point of attack in the search for the cause of immunity that is not found in the heterœcious rusts of grasses, and when the studies on this point have been completed it is hoped that new light, at least, will be thrown on the question of disease resistance.

Relation of vigor to resistance.—The theory that vigor of growth is correlated with resistance, as suggested by some American writers on the subject, can not be accepted, for many resistant plants are quite small and never produce strong shoots. The trials of the last two seasons of two equally resistant strains of Argenteuil stock from local growers at Concord show no relation between resistance and vigor. About 450 one-year-old seedlings of each strain were planted in 1908 side by side on uniform land and under uniform treatment. When they were cut for a short time in 1910 each day's yield was separated into giant and common grades, using the local grading system. One lot gave a total yield over a period of 35 days, from April 23 to May 28, of $142\frac{9}{16}$ pounds divided into $106\frac{13}{16}$ pounds of giant and $35\frac{3}{4}$ pounds of common. The second lot gave in the same period only $65\frac{13}{16}$ pounds total cut divided into $14\frac{1}{2}$ pounds giant and $51\frac{5}{16}$ pounds common. The details of the record are presented in Table IV.

[1] Ward, H. M. Recent Researches on the Parasitism of Fungi. Annals of Botany, vol. 19, 1905, p. 21.

TABLE IV.—*Yield from five 300-foot rows of Argenteuil asparagus, showing comparison of large and small strains, seasons of 1910 and 1911.*

Date.	Large strain.						Small strain.					
	Giant.			Common.			Giant.			Common.		
	Weight.			Weight.			Weight.			Weight.		
	Pounds.	Ounces.	Stalks.	Pounds.	Ounces.	Stalks.	Pounds.	Ounces.	Stalks.	Pounds.	Ounces.	Stalks.
1910.[1]												
April:												
23	1	14	20	0	8	15	0	0	0	0	11	20
25	1	13	20	0	9	19	0	8	7	1	3	29
27	5	10	55	2	8	57	0	13	11	2	1	61
28	6	2	63	1	4	34	0	10	9	2	1	76
May:												
2	14	7	126	2	8	65	1	14	23	6	5	182
4	7	0	73	2	2	45	1	9	20	2	8	60
10	5	7	45	1	4	29	0	12	9	1	11	41
13	11	6	96	3	2	73	0	10	9	4	4	135
16	7	10	70	2	5	74	1	5	16	3	12	120
18	8	3	72	2	6	66	1	14	25	4	7	142
20	4	2	38	1	5	35	0	15	12	2	15	91
21	4	10	45	2	10	66	0	10	8	2	13	108
23	6	1	55	2	4	60	0	13	10	3	13	123
24	4	10	42	6	2	54	0	7	6	2	14	101
25	6	15	71	3	1	90	0	8	7	4	2	146
26	3	12	40	1	6	48	0	7	6	2	3	85
27	2	15	31	2	5	51	0	8	6	1	9	50
28	3	4	31	1	15	55	0	5	4	2	1	69
Total	106	13	1,073	35	12	936	14	8	188	51	5	1,739
1911.[2]												
May:												
6	0	11	10	0	5	10	0	2	2	1	0	32
8	6	10	71	3	7	82	1	8	22	4	7	153
9	8	9	82	3	8	85	1	4	15	5	0	133
10	15	5	127	3	12	86	2	8	28	8	10	208
11	21	8	189	4	8	105	4	11	51	8	10	233
12	25	7	211	3	6	84	4	4	50	7	10	214
13	16	10	142	2	13	61	2	12	30	5	11	147
14	12	3	99	1	8	41	2	8	34	2	2	65
15	8	1	72	2	0	45	2	11	33	2	11	80
16	10	13	89	2	7	61	2	1	25	4	8	129
17	8	4	67	2	7	59	2	7	30	5	1	132
18	9	3	83	2	10	62	1	9	18	4	12	132
19	8	3	74	2	13	80	1	10	18	5	11	146
20	6	0	58	1	7	33	1	6	17	2	14	78
21	11	10	103	3	8	88	2	9	27	7	10	192
22	8	9	77	5	1	117	2	11	28	9	5	246
23	8	5	74	2	8	69	2	0	23	5	4	161
24	1	3	13	0	10	20	0	1	1	0	9	23
26	8	14	79	1	10	42	3	6	39	4	0	112
27	7	14	72	1	13	44	2	13	34	4	0	108
28	13	9	121	5	1	113	3	4	38	8	3	224
29	9	7	89	5	10	140	2	10	33	5	13	184
30	7	4	60	4	13	125	1	5	16	4	8	128
31	5	6	48	3	3	70	1	11	19	3	14	101
June:												
1	7	0	60	3	5	83	1	11	21	6	3	176
2	6	6	53	2	8	67	0	11	9	3	12	114
3	8	2	80	3	6	98	1	10	20	3	3	108
4	4	12	48	2	11	67	0	11	9	1	15	49
5	6	4	62	1	13	56	1	6	18	3	6	104
7	5	9	51	1	14	55	2	0	23	3	14	113
8	3	0	30	1	3	37	1	9	20	2	12	103
9	5	14	59	2	9	67	1	7	20	3	10	105
10	7	10	67	4	4	111	1	15	23	5	9	164
11	4	0	40	3	5	88	1	13	20	2	1	50
12	4	12	47	1	1	20	1	2	16	4	2	137
14	2	13	30	1	11	48	1	3	15	2	6	70
Total	305	10	2,737	100	6	2,519	70	12	845	164	10	4,654

[1] Total yield in 1910: Large strain—2,009 stalks, weighing 142 pounds 9 ounces (average weight per stalk, 1.14 ounces); small strain—1,927 stalks, weighing 65 pounds 13 ounces (average weight per stalk, 0.54 ounce).

[2] Total yield in 1911: Large strain—5,256 stalks, weighing 406 pounds (average weight per stalk, 1.23 ounces); small strain—5,449 stalks, weighing 235⅜ pounds (average weight per stalk, 0.69 ounce).

The results in 1911, showing the yield for a full season, were more conclusive. Again lot 1 was far superior in size and total yield, giving 406 pounds total, of which 305⅝ pounds were of giant grade and 100⅜ pounds common. Lot 2, while actually producing more stalks in the season, had only 235⅜ pounds total, 70¾ pounds giant and 164⅝ pounds common. The record for 1911 is also shown in Table IV. If there was any difference, the advantage in rust resistance is in favor of lot 2; moreover, about 10 of the best plants were reserved out of lot 1 as breeding parents and the cut is thus perceptibly reduced. In the region around Concord it has been noticed frequently that the poorer parts of the field had less rust when other conditions were equal, so that the application of chemical fertilizers has been held by some farmers to be the cause of the rust.

BREEDING.

The real work of breeding started in the spring of 1909. Many questions of importance in regard to methods had to be settled, for to a certain extent we were on unknown ground. Asparagus was generally recognized as a diœcious plant, but several writers and observers had suggested that parthenogenetic seeds were sometimes produced. The relative dominance of rust resistance in heredity was uncertain in asparagus. Biffen[1] in his work with disease resistance in the small grains had shown an apparent dominance of susceptibility, but in asparagus there is no question at present that the heterozygous forms are intermediate in resistance. The possibility of obtaining a combination between strains that would give first-generation hybrid vigor was important, and above all was the hope of finding two parent plants that would give a highly uniform progeny in rust resistance and vigor.

In starting the work a study had to be made of the natural and artificial methods of pollination. Means had to be devised to control the pollination work so that reliable pedigrees could be established. The paragraphs that follow comprise an account of the observations made and the resulting methods developed and now in practice on the different phases of these problems.

SEX.

Asparagus officinalis is functionally diœcious, but the flowers on both types of plants contain rudiments of the organs of the opposite sex. Under field conditions asparagus apparently requires the aid of insects to secure proper pollination. As a rule, no seed is set without the aid of bees and other insects carrying pollen from the flowers

[1] Biffen, R. H. Journal of Agricultural Science, vol. 1, 1905, p. 40; vol. 2, 1907, pp. 109–128.

of male plants to the stigmas of the flowers on the female plants. Hermaphrodite plants occur now and then, but so far in our experiments can not be considered a factor in seed production. In the flowers of the typical female plant the rudiments of stamens (Pl. VII, fig. 2) exists, but the writer has never seen one developed sufficiently to even suggest the possibility of self-pollination. On the other hand, the male plants often show a well-developed ovary with style and stigma and sometimes even a typical stigmatic surface. The great majority of male flowers, however, lack a well-developed ovary, the rudiment being about half the size of the normal ovary of the female flower and lacking any stigmatic development (Pl. VII, fig. 1), the style often being completely abortive. The hermaphrodite plants mentioned above are always of the male type, the flowers being for the greater part pure male in that they lack the complete and functional ovary. In one wild male plant examined the flowers at the extremities of the branches were typically female with well-developed stigma and abortive anthers. This male had been used for pollination work in testing rust resistance of select plants. Another hermaphrodite plant which produced seed that would germinate and make healthy, vigorous plants had many flowers whose ovaries lacked the stigmas. The berries on these hermaphrodite plants are very small and rarely have more than one seed in them. The seeds are usually peculiar in that the seed coats are not entirely developed. The seeds appear mottled black and white, varying from the white of the uncovered endosperm in the smaller seeds to well-covered, entirely black seeds in which the coats have had their normal development and have completely covered the endosperm (Pl. IX, fig. 1). These small seeds make weak plants and in many cases abnormal ones, but the larger, better developed seeds make healthy seedlings of normal type. As yet these seedlings have not been observed in bloom, so the sex inheritance is unknown.

POLLINATION.

During the blooming period of 1909 and again in 1910 branches of pistillate plants were covered with paraffin paper bags to exclude pollen-carrying insects (Pl. VIII). Although more than a hundred of these check trials were made, in no case did any seed set from flowers that opened under the bags. The ovaries would swell and apparently start to develop good berries, but after reaching about one-third of the ordinary diameter they would turn yellow and drop off. The uncovered flowers on the same stem set seed abundantly (Pl. IX, fig. 2). That this failure to set seed is due to a lack of pollination is shown by the large number of seeds secured under bags when

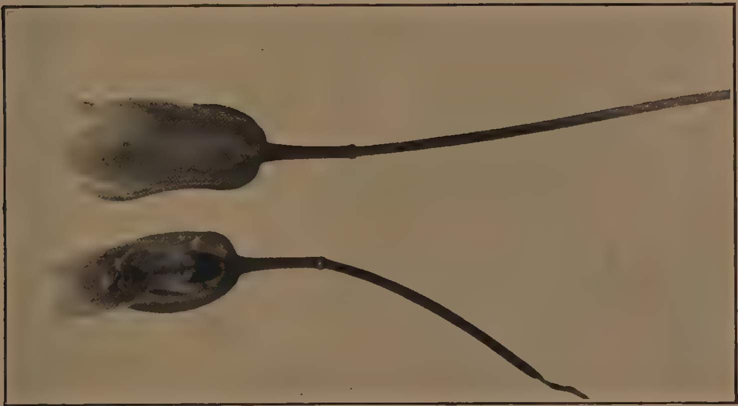

FIG. 1.—MALE FLOWERS, THE LOWER WITH SOME OF ITS PERIANTH LOBES REMOVED TO SHOW THE STAMENS AND RUDIMENTARY OVARY. THE PERIANTH LOBES ARE LONGER THAN IN THE FEMALE FLOWER. ×5.

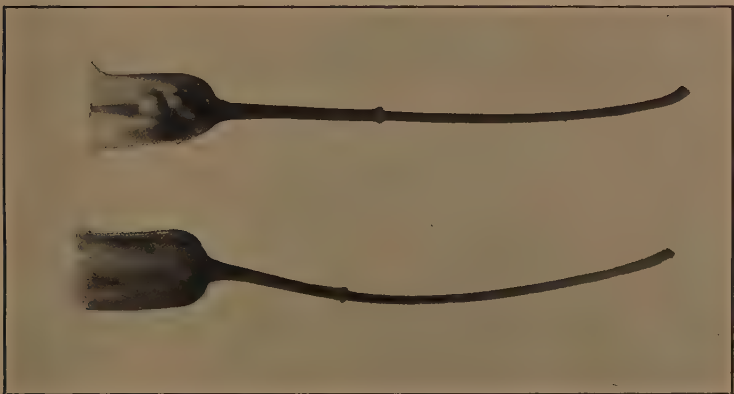

FIG. 2.—FEMALE FLOWERS, THE UPPER WITH SOME OF ITS PERIANTH LOBES REMOVED TO SHOW THE OVARY AND RUDIMENTARY STAMENS. THE PERIANTH LOBES ARE SHORTER THAN IN THE MALE FLOWERS. ×5.

FLOWERS OF ASPARAGUS OFFICINALIS.

FEMALE ASPARAGUS PLANT WITH BRANCHES COVERED BY "GLASSINE" BAGS TO KEEP INSECTS FROM POLLINATING THE FLOWERS WITH POLLEN FROM UNKNOWN MALES, THIS PLANT BEING USED TO TEST THE COMPARATIVE RESISTANCE TRANSMISSION OF SEVERAL MALES.

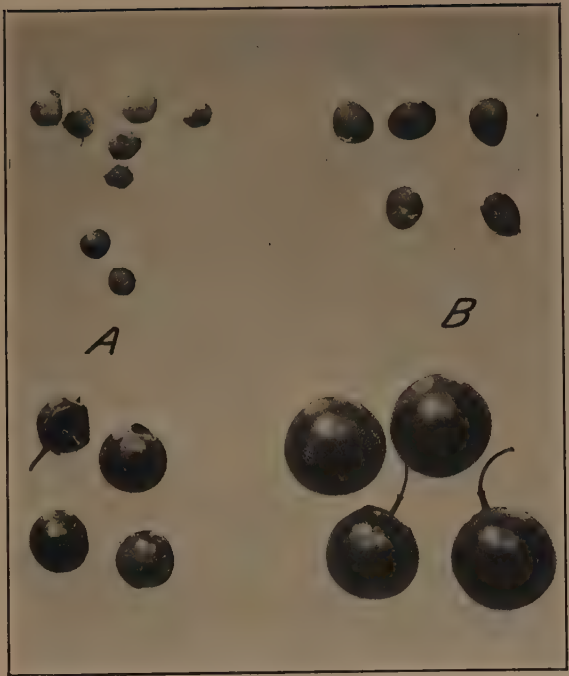

FIG. 1.—ASPARAGUS FRUIT AND SEED. *A*, FROM A HERMAPHRODITE PLANT. EACH BERRY CONTAINS ONE SEED WHICH OFTEN LACKS ALL OR PART OF THE BLACK SEED COAT. *B*, FROM A NORMAL PLANT.

FIG. 2.—ASPARAGUS STEM, SHOWING THE EFFECT OF BAGGING FLOWERS WITHOUT POLLINATION. THE TOP OF THE STEM WAS COVERED DURING THE BLOOMING SEASON, WHILE THE LOWER BRANCHES BLOOMED IN THE OPEN AND WERE POLLINATED BY BEES.

FIG. 1.—SEEDLINGS OF 1909, IN SEPTEMBER, 1909, AFTER A SEVERE ATTACK OF RUST. ROWS 3, 5, 6, 7, AND 12 SHOW RESISTANCE.

FIG. 2.—PEDIGREE SEEDLINGS OF 1910, IN SEPTEMBER, 1910, B136-4 × A7-83, SHOWING RUST RESISTANCE.

FIG. 3.—PEDIGREE SEEDLINGS OF 1910, IN SEPTEMBER, 1910, B136-4, OPEN FERTILIZED, SHOWING LACK OF RESISTANCE AND VIGOR.

ASPARAGUS SEEDLINGS, SHOWING COMPARATIVE RUST RESISTANCE.

the flowers were hand-pollinated. The insect visitors to the asparagus flowers are largely bees of different kinds. The honey bee is most plentiful during the blooming season, and at this time of the year practically all of the pollen that comes into hives that are near asparagus fields is the rich, orange pollen from the staminate asparagus flowers. Apparently a large amount of nectar is also produced. This is shown particularly in flowers under bags where the bees have been kept away until the flower is old, when it is so abundant as to interfere with pollination. In addition to the honey bee many small wild bees frequent the asparagus flowers. Some of these small bees are a nuisance in the pollination work, apparently being especially attracted by the extra quantity of honey in the protected flowers.

The wind seems to play little part in pollination, as the male flowers retain their load of pollen until they begin to wither unless it is removed by a bee. The pollen hangs together in masses and does not become powdery until the flower dries up.

The anthers of the staminate flowers dehisce throughout the day, but by far the greater portion open in the morning hours. On a bright, sunny day they are nearly all open by the time the dew is gone. Cold, damp weather seems to prevent the anthers from opening, so that after a long spell of rainy weather a large number of flowers will be spoiled, as the anthers do not open well except when fresh. There is quite a range of variability in this respect and also as to the time the anthers open in the morning. Some days when the atmosphere was moist some staminate plants could not be used in pollination work until an hour or so after most of the others, and on misty or damp, cloudy days these plants would refuse to shed their pollen at all, while plants near them would yield abundant supplies.

METHODS OF HAND POLLINATION.

In the work of hand pollination in asparagus very little apparatus is required. The principal requirement is to prevent the random pollination of the pistillate flowers by insect visitors. So far in this work we have largely depended on paraffin paper bags. A good quality of paper known as "glassine" is used. This paper is nearly transparent and is tougher and wears better than any other paraffin paper obtainable at a reasonable price. During the spring of 1910 many of these bags went through a three-days' storm of wind and rain without injury. The bags are attached and held on by short pieces of No. 18 office wire to which is attached a small eyelet string tag for records. The office wire is purchased in small rolls and cut up with a pair of shears into pieces about 4 inches long. The bags are

placed over the branches of the female plant, gathered at the mouth, and firmly held by bending a piece of wire around the bag about an inch or two above the mouth. Ordinarily two branches are included in the bag in order to brace each other and prevent the wind from whipping the bags around or breaking the stems. This wire is a great time saver over twine, as it does away with tying and untying at a time when minutes are valuable. This wire is also used in tying the main stalks to stakes to keep them standing against storms. Plain copper wire of equal weight is apt to cut and wear into the stems or through the bags.

In the season of 1911, cages constructed of ordinary fly-screen wire cloth were used to cover the select plants both male and female. It was discovered later in the season that a very small wild bee was squeezing in through the meshes and pollinating flowers. In the future a finer mesh copper-wire screen will be used. The season of 1911 was exceptional for days of extreme heat. Many of the branches inclosed under the glassine bags died after they had set fruit. Such berries never developed viable seed. Asparagus throughout its development is very partial to good ventilation and any protective measures for pedigree work must take this into account.

The female plants to be tested can be bagged about the time the first flowers are ready to open. At this time the branches are tough enough to bend readily without breaking. Flowers that have opened are picked off before the branch is bagged.

The work of pollination is best done in the morning hours just after the dew is gone. The desired male plants are visited and a collection made of flowers undisturbed by bees or other insect visitors. These flowers are placed in small shell vials lined with absorbent paper and with a stopper of absorbent cotton. The vial keeps them from drying out and losing their pollen and from becoming mixed with flowers from other plants. All vials used should be properly labeled to prevent mistakes.

In selecting male flowers only those are taken whose anthers have dehisced their pollen. The pollen in a freshly opened flower clings in an orange mass around the stamens at the throat of the bell-shaped flower. Flowers that have been visited by bees have lost most of this mass and the lighter color of the anther walls gives a much lighter color to the anther cluster. These flowers should be rejected, as they are liable to be mixed with foreign pollen.

In pollinating, the bag is removed from the female branch. A flower from the bottle of male flowers is taken out and grasped lightly in the right hand, using the thumb and finger or a pair of forceps. With the left hand a flower on the female branch is carefully bent

into such a position that it can be touched with the pollen mass in the male flower. If the flowers are brought lightly together so as not to injure the stigma, the stigmatic surface will be well covered with pollen and in the course of a few days the ovary will swell into a full-sized berry. With a little practice pollination becomes a matter of routine work. The whole male flower is used in pollination, and this method has proved very satisfactory, doing away with the use of brushes or other pollinating devices which are apt to cause mixing of pollen from different males. After all the female flowers that are open are pollinated the bag is replaced and the tag marked with identifying data. One male flower will usually pollinate ten or more female flowers, leaving enough pollen on each stigma to be plainly visible to the naked eye.

CARE OF SEED.

After the various pollinations are made on select plants in spring and early summer considerable time must elapse before the seed is ripe and ready for harvest. Cultivation is apt to break off branches unless great care is used. Asparagus beetles must be guarded against. The various accidents considerably reduce the percentage of seed set. The berries should not be harvested until they are ripe and soft, otherwise the seed is apt to be shriveled and of poor quality. The seed when in lots of less than a hundred berries is harvested by picking the berries from the plants in the field and placing them in small manila bags, which are labeled on the outside with sufficient data to distinguish the different lots and stored temporarily in racks in a well-ventilated room. After the berries have begun to wither they can be stored in ventilated storage boxes without injury until such time as it is convenient to clean them. The lots of berries are crushed and washed in water, the pulp and skins washed out, and the clean seed allowed to dry thoroughly. The seed is then placed in shell vials, labeled and corked, and stored for next year's planting. The seed of *Asparagus officinalis* retains its viability for several years if properly handled.

METHOD OF TESTING PROGENY.

The first work in testing transmission of relative rust resistance was in the summer of 1909. The previous fall samples of seed had been saved from various plants of different degrees of resistance. Twelve lots of these seeds were planted in duplicate in short rows in seed flats on July 13. When the shoots appeared, July 26, and for several succeeding days, fresh uredospore material was dusted over the flats. The following table shows the relative rust resistance of the rows of these seedlings from observations made September 3, 1909.

TABLE V.—*Duplicate test of seedlings of 1909 from plants of varying rust resistance to show relative transmission of susceptibility.*

Row.	Source of seed.	Type of plant.	Rank of seedlings in resistance.		
			First lot.	Second lot.	Average.
1	A1-6	Badly rusted, near rusty bed	7	9	8
2	A3-61	Very resistant female	6	5	5.5
3	A4-7	Resistance good	3	7	5
4	A4-17	Resistance fair	10	8	9
5	A7-5	Resistance good	4	3	3.5
6	A7-15	do	2	4	3
7	A7-25	do	5	2	3.5
8	B24-27	Very rusty	11	10	10.5
9	B24-28	do	9	11	10
10	Old field	Rusty	12	12	12
11	do	Resistant	8	6	7
12	Frank Wheeler; old bed	Best resistant female	1	1	1

An inspection of the table shows that the asparagus plants transmit resistance to their offspring in about the same relative degree that they resist the rust themselves. Plate X, figure 1, is from a photograph taken in September, 1909, of lot 1 of this set of duplicates, showing plainly the effect of rust on the lots.

This experiment settled the question of the value of rust resistance in the plant as a mark of transmitting power. After this preliminary trial, plans were laid to test the lots of seed that were obtained from our hand pollinations in 1909. In addition to the hand-pollinated lots a sample of open-fertilized seed has usually been saved for comparison in the progeny tests.

In January, 1910, as many lots of seed as could be conveniently handled were planted in seed flats in the greenhouse at Washington. Studies of the germination and growth of these lots were made and correlations measured between various characters. In the discussion on the following pages these seedlings are referred to as the greenhouse seedlings of 1910 to distinguish them from other lots of asparagus plants under observation.

USE OF BIOMETRY.

CORRELATION STUDIES.

The use of statistical methods in breeding is becoming more and more popular and in many lines is really necessary. The presentation of biometrical studies is now rather common in experiment-station bulletins. If breeding is to be put on a progressive scientific basis this type of work will of necessity become more prevalent. The excessive presentation of correlation studies as such should be discouraged among practical workers. The value of any work in correlation depends on the possible use that can be made of the facts in a practical way. The great number of interrelated biologic phenomena that occur in any plant need to be understood before one character can be used as a basis for selection for a correlated character.

In the study of a plant like asparagus, where selections must be made for rust resistance and yield, two desired characters which do not show simultaneously, in order to do efficient work some other correlated character must be substituted for yield. Again, the young seedling must be compared with the bearing plant several years later so that undesirable stock can be discarded without the necessity of planting large fields with plants of unknown qualities. Before any correlation studies were made all stocks were planted in permanent beds and grown for years without selection. Since 1910 no untested plants have been carried beyond the first season in the seed bed, all the poor stock being discarded the first year. In this way a great saving in field space is accomplished. Of course, care must be used in basing selections on one character to get plants good in another character. Where the correlation runs above 0.75 very good results are usually obtained.

Correlation tables serve a good purpose in checking up the reliability of tests. The use of duplicate plantings or trials year by year to secure data on average performance are valuable only as they show a high correlation.

Correlation tables are used in our breeding wherever possible to show the reliability of the observations made. This feature is illustrated in Table VI, in which the heights of several lots of the greenhouse seedlings on February 7, 1910, are correlated with the heights of the same lots four days later, showing that the observations taken on either of the two dates were satisfactory.

TABLE VI.—*Correlation between the heights of the tallest plants in 66 lots of progeny rows of greenhouse seedlings of 1910, taken four days apart, February 7 and February 11, 1910.*

[Heights on February 11, subject; heights on February 7, relative. Coefficient of correlation, 0.941±0.013.]

Heights on February 11.	Heights on February 7 (¼-inch units).																			Frequency.	Departure from mean.
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
¼-inch units:																					
18	1																			1	−12
19																				0	−11
20			1																	1	−10
21																				0	− 9
22																				0	− 8
23																				0	− 7
24								1												1	− 6
25							1			1										2	− 5
26									2											3	− 4
27										2	2									4	− 3
28										1		3		1	1					6	− 2
29												5	1	1	1					8	− 1
30												1	1	3	1					6	0
31													3	4	4	2				13	+ 1
32														1	4	3		1		9	+ 2
33															2	1	1			4	+ 3
34															1	1	1	1		4	+ 4
35																		2		2	+ 5
36																	1			1	+ 6
37																	1		1	2	+ 7
Frequency	1	0	1	0	0	0	1	1	2	4	2	9	5	10	14	7	4	4	1	66	
Departure from mean	−12	−11	−10	−9	−8	−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	....	

DUPLICATE TESTS.

The use of duplicate plats in testing varieties or in breeding or selection is important in checking up results. Unless the correlation is high, say around 60 to 70 per cent, the test should be looked on with doubt. When these data are presented in the form of two overlaid curves, the observer is liable to be misled, as the correlation is hard to judge; but this form of presentation is used by many writers, is easily constructed, and can be used to show the relation of more than two characters at the same time. Still, the fact remains that the measure of the correlation is indefinite.

Duplicate plantings were made of 33 lots of the greenhouse seedlings, and from them many interesting facts were developed. Table VII presents the correlation between the tallest plants in the duplicate rows from measurements taken February 11, 1910. The correlation between the average height of all the plants in the rows on the same date is shown in Table VIII, and Table IX shows the correlation between the tallest plant in the row and the average of all the plants in the row. In dealing under ordinary circumstances with progeny lots of plants varying in a normal way, these tables show whether rapid selections can be based on the best individual in each lot. It appears that there is a high probability that an experimenter is perfectly safe in basing selections of future progeny lots on a comparison of the means or of either the high or the low extreme.

TABLE VII.—*Correlation between the tallest plants in two lots of duplicate plants of progeny lots of greenhouse seedlings of 1910, February 11, 1910.*

[Lot 1, subject; lot 2, relative. Coefficient of correlation 0.876±0.028.]

Height of first lot.	Height of second lot (¼-inch units).																			Frequency.	Departure from mean.
	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40		
¼-inch units:																					
19	1																			1	−14
20																				0	−13
21																				0	−12
22																				0	−11
23																				0	−10
24																				0	− 9
25																				0	− 8
26						1														1	− 7
27																				0	− 6
28																				0	− 5
29							1		1											2	− 4
30								1												1	− 3
31									1		1		1							3	− 2
32									1	1	2									4	− 1
33										3			2							5	0
34										1	1			1						3	+ 1
35													1	2	1		1			5	+ 2
36															1		2			3	+ 3
37													1	1					1	3	+ 4
38															1					1	+ 5
39																				0	+ 6
40																				0	+ 7
41																1				1	+ 8
Frequency	1	0	0	0	0	1	1	1	3	5	4	0	5	4	3	1	3	0	1	33	
Departure from mean	−11	−10	−9	−8	−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	+7	......	

TABLE VIII.—*Correlation between the average heights of greenhouse seedlings of 1910 in two duplicate lots of progeny, February 11, 1910.*

[Second lot, subject; first lot, relative. Coefficient of correlation 0.826±0.035.]

Average height of second lot.	Average height of first lot (¼-inch units).																	Frequency.	Departure from mean.
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33		
¼-inch units:																			
20	1																	1	−8
21																		0	−7
22																		0	−6
23																		0	−5
24								1		2								3	−4
25																		0	−3
26										3			1					4	−2
27										2		1	1	2				6	−1
28										1	2			2	1			6	0
29													2		1			3	+1
30											1			1		2		4	+2
31													1	1	1			3	+3
32																		0	+4
33															1		1	2	+5
34																	1	1	+6
Frequency	1	0	0	0	0	0	0	1	0	8	3	1	5	6	4	2	2	33	
Departure from mean	−11	−10	−9	−8	−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	....	

TABLE IX.—*Correlation between height of tallest plant and mean height of progeny rows of greenhouse seedlings of 1910, February 11, 1910.*

[Mean height, subject; height of tallest plant, relative. Coefficient of correlation 0.901±0.016.]

Mean height of row.	Height of tallest plant in row (inches).																							Frequency.	Departure from mean.
	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	8.50	8.75	9.00	9.25	9.50	9.75	10.00	10.25		
Inches:																									
4.25	1																							1	−2.75
4.50																								0	−2.50
4.75																								0	−2.25
5.00				1																				1	−2.00
5.25																								0	−1.75
5.50																								0	−1.50
5.75								1																1	−1.25
6.00									1	1		1												3	−1.00
6.25																								0	− .75
6.50											3	3	3	2	1									12	− .50
6.75													3	3	1	2				1				10	− .25
7.00													2	3		1								6	0
7.25															2		5			1				8	+ .25
7.50															1	4	3	1	1			1		11	+ .50
7.75																	1	4		1				6	+ .75
8.00																			2					2	+1.00
8.25																			1	2			1	4	+1.25
8.50																		1						1	+1.50
Frequency	1	0	0	1	0	0	0	1	1	1	3	4	8	8	5	7	9	6	4	5	0	1	1	66	
Departure from mean	−3.50	−3.25	−3.00	−2.75	−2.50	−2.25	−2.00	−1.75	−1.50	−1.25	−1.00	− .75	− .50	− .25	0	+ .25	+ .50	+ .75	+1.00	+1.25	+1.50	+1.75	+2.00		

USE OF CORRELATION STUDIES IN BREEDING WORK.

The value of studies in correlation to the practical work of plant improvement, while not questioned by those familiar with statistical methods, has been doubted by those not in the habit of doing accurate

work. One or two examples will show the possibilities of the use of correlation.

The relation of the size of the asparagus stalk in the fall to the next year's cut is interesting, as it is necessary in selecting rust-resistant plants in the fall to pick those that will give large-sized shoots. Studies of several plants in row A1 presented in Table X give a fair idea of the value of large-sized fall growth in determining large-sized spring growth. In the same way the total yield should be taken into consideration. This quality is hidden at the time of selection and must be correlated with total production of stalks in the field in the fall. This relationship was worked out with the plants in row A1 and the result is shown in Table XI. Certainly when the correlation is as high as 0.8 the observer should make an almost perfect selection by using the correlated character to pick the very best plants.

TABLE X.—*Correlation between the diameters of the largest stalks in 86 hills of row A1 in the fall of 1909 and in the largest stalks cut in the spring of 1910.*

[Diameters of 1909, subject; diameters of 1910, relative. Coefficient of correlation 0.575±0.050.]

Fall of 1909.	Spring of 1910 (⅛-inch units).											Frequency.	Departure from mean.
	2	3	4	5	6	7	8	9	10	11	12		
⅛-inch units:													
2			1									1	−2
3	1	1	8	7	3							20	−1
4	1	4	3	6	12	5	1					32	0
5		1	2	3	5	7	4	1				23	+1
6					2	3	1				1	7	+2
7						1	2					3	+3
Frequency	2	6	14	16	22	16	8	1	0	0	1	86	
Departure from mean	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	......	

TABLE XI.—*Correlation between cross section of stems in fall of 1910 and cut in spring of 1911 on 82 producing plants of row A1.*

[Fall stem area, subject; spring cut area, relative. Coefficient of correlation 0.811±0.025.]

Fall of 1910.	Spring of 1911 (square inches).																	Frequency.	Departure from mean.
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33		
⅛-inch square units:																			
10	13	4		1														18	−2
30	2	6	6	2		2												18	−1
50	1	3	5	3	1	2	1											16	0
70			1	6	3	1	1	2										14	+1
90				1	1	1				1								4	+2
110			1		1	2												4	+3
130		1				1	1											3	+4
150										2								2	+5
170												1						1	+6
190																		0	+7
210																		0	+8
230																		0	+9
250											1							1	+10
270																	1	1	+11
Frequency	16	14	13	13	6	9	3	2	0	3	1	1	0	0	0	0	1	82	
Departure from mean	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+10	+11	+12	+13	....	

A most interesting interrelation comes in the size of the seedling to the weight of the seed. It was early noticed that the greenhouse lots of seedlings showed striking differences between progeny lots from different female plants. Wherever enough seed remained unplanted to give a fair average, the seed weight was determined and a comparison made with the average height of the seedlings in the progeny rows. Table XII was obtained with a coefficient of 0.780. Where future size depends on the start the young seedling gets in the bed, the tremendous importance of the use of large seed is at once apparent. To further test this correlation, 100 seeds from plant C13–5–1, open fertilized, were sown in 1910 under uniform conditions of moisture, heat, and light in a soil of uniform texture. Each seed was weighed to 0.001 gram, the germination record was made, and the height of each seedling was measured daily. No effect of size of seed on germination could be determined, but the size of the individual seed showed a very strong influence on the height and rate of growth. (Table XIII.) Where the individual seed is taken into account the correlation is lower than where the average of several is taken, on account of the varying hereditary tendencies in different seed of the same weight.

TABLE XII.—*Correlation between average weight of seed and average height of greenhouse seedlings of 1910 for 42 progeny lots on February 11, 1910.*

[Height, subject; weight, relative. Coefficient of correlation 0.780±0.042.]

Height of seedlings.	Average weight of seed (milligrams).											Frequency.	Departure from mean.
	19	20	21	22	23	24	25	26	27	28	29		
Inches:													
5.75	1	....	....	....	....	....	....	....	....	....	....	1	−1.00
6.00	1	2	....	1	1	....	....	....	....	....	....	5	− .75
6.25	....	1	1	....	....	....	....	....	....	....	....	2	− .50
6.50	....	2	1	1	....	....	....	....	....	....	....	4	− .25
6.75	....	3	1	1	1	1	2	....	....	....	....	9	0
7.00	....	....	....	3	4	2	1	....	....	....	....	10	+ .25
7.25	....	....	....	....	1	....	....	....	1	....	....	2	+ .50
7.50	....	....	....	....	2	1	2	....	....	....	....	5	+ .75
7.75	....	....	....	....	....	....	....	1	1	....	1	3	+1.00
8.00	....	....	....	....	....	....	....	....	1	....	....	1	+1.25
Frequency	2	8	3	6	9	4	5	1	3	0	1	42	
Departure from mean	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	......	

TABLE XIII.—*Correlation between height of shoot and weight of seed in 100 seedlings from weighed seed of C13–5–1, open fertilized, grown under control conditions in greenhouse at Washington in 1910.*

[Height of first shoot April 9, 1910, subject; weight of seed in milligrams, relative. Coefficient of correlation 0.41±0.056.]

Height of shoot.	Weight of seed in milligrams.															Frequency.	Departure from mean.
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26		
Inches:																	
3			1													1	−2.50
3.25																0	−2.25
3.50					1	1		1								3	−2.00
3.75		1			1											2	−1.75
4		1			1	1		1								4	−1.50
4.25								2								2	−1.25
4.50								1	3	1						5	−1.00
4.75						3	2			1						6	− .75
5				2	1		2	1				1				7	− .50
5.25				2	2	1	1		3	1						10	− .25
5.50	2	1		1		1	1	1	1	1	2			1		12	0
5.75			1	1	4	3	1		1	4				1	1	17	+ .25
6					2	2	1	1	1		1					8	+ .50
6.25				1	1			1	1		1					5	+ .75
6.50							4		2		1	1				8	+1.00
6.75								1			3	1	1			5	+1.25
7												1				1	+1.50
7.25																0	+1.75
7.50											1	1			1	3	+2.00
7.75										1						1	+2.25
Frequency	2	3	2	7	13	12	12	10	12	9	8	5	1	2	2	100	
Departure from mean	−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	+7	......	

Table XIV is introduced in order to show that the size of the young asparagus seedling is important in determining the future size of the plant. This table shows the correlation existing between the average heights of 85 progeny lots while in the seed flats in the greenhouse at an age of three weeks and the average of the same progeny lots in their permanent place in the field. The factor of crowding, which aids the stronger plants and retards the weaker ones, was eliminated by placing the plants in individual pots February 13 and so maintaining them until they were transplanted to the field where they are just beginning to show the effects of crowding in the fall of 1911.

TABLE XIV.—*Correlation between average height of greenhouse seedlings in progeny lots February 11, 1910 (in ½-inch units), and their average height September, 1910 (in inches).*

[Height in September, subject; height in February, relative. Coefficient of correlation 0.552±0.048.]

Height in September.	Average height of seedlings February 11, 1910 (½-inch units).															Frequency.	Departure from mean.
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34		
Inches:																	
9	...	...	1	1	...	...	...	...	...	...	...	...	...	...	...	2	−6
10	1	...	...	...	...	...	2	...	...	...	...	...	...	...	...	3	−5
11	...	...	...	1	1	1	...	3	...	...	...	...	...	...	...	6	−4
12	...	...	...	...	2	...	...	...	1	1	...	...	...	...	...	4	−3
13	...	...	...	...	1	...	3	3	4	1	2	...	...	...	...	14	−2
14	...	...	...	...	3	...	...	1	3	...	...	1	...	...	...	8	−1
15	...	...	...	...	1	...	2	1	3	1	2	1	...	...	1	12	0
16	...	...	...	...	...	1	1	2	3	1	1	1	1	2	...	13	+1
17	...	...	...	...	...	...	1	3	...	...	1	1	1	...	...	7	+2
18	...	...	...	...	...	...	...	1	1	...	...	...	1	...	...	3	+3
19	...	...	...	...	...	...	1	...	1	1	1	2	...	...	...	6	+4
20	...	...	...	...	...	...	...	...	...	1	1	...	...	...	...	2	+5
21	...	...	...	...	...	...	...	1	...	...	...	...	2	...	...	3	+6
22	...	...	...	...	...	...	...	...	1	...	...	...	...	1	...	2	+7
Frequency	1	0	1	2	8	2	10	15	17	6	8	6	5	3	1	85	
Departure from mean	−8	−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	....	

In continuing the work with the greenhouse seedlings after they were removed to the field in May, 1910, further correlations have been studied. While these progeny lots are not exactly a random sample, in many respects they answer the purpose of one, the population being distributed in monomodal and often nearly normal variation curves.

In making selections among the young seedlings a general tendency among growers is to assume that height is a good index of large-sized shoots in future years in the cutting bed. According to the tables constructed on the data of height in 1910 and stalk diameter of the greenhouse seedlings in 1911 (Table XV), there is a correlation of 0.634 ±0.013. This result is supported by notes from row A1, where the total area of the cross section of the fall stems in 1910 was compared with the total area of the cross section of the shoots cut in the spring of 1911, as shown in Table XI (p. 36).

TABLE XV.—*Correlation between height in 1910 (inches) and diameter of largest stalk in 1911 ($\frac{1}{16}$-inch units) of the greenhouse seedlings of 1910.*

[Height in 1910, subject; diameter in 1911, relative. Coefficient of correlation 0.634±0.013.]

Height in 1910.	Diameter of stalks in 1911 ($\frac{1}{16}$-inch units).														Frequency.	Departure from mean.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
Inches:																
4	....	1	....	1	....	....	....	....	....	....	....	....	....	....	2	—11
5	3	....	1	1	....	....	....	....	....	....	....	....	....	....	5	—10
6	1	2	2	4	3	....	....	....	....	....	....	....	....	....	12	— 9
7	....	4	7	5	8	2	2	1	....	....	....	....	....	....	29	— 8
8	....	3	4	9	4	9	1	1	....	....	....	....	....	....	31	— 7
9	....	4	10	18	12	11	1	3	....	....	....	....	....	....	59	— 6
10	....	....	9	15	18	5	3	....	....	....	....	....	....	....	50	— 5
11	....	3	9	16	20	14	11	5	....	1	....	....	....	....	79	— 4
12	....	....	7	10	24	18	6	2	....	....	....	....	....	....	67	— 3
13	....	1	6	10	20	28	6	3	....	1	....	....	....	....	75	— 2
14	....	1	3	12	13	30	14	9	2	1	....	....	....	....	85	— 1
15	....	....	3	6	15	28	17	10	....	....	....	....	....	....	79	0
16	....	....	2	3	11	29	11	10	4	2	1	....	....	....	73	+ 1
17	....	....	1	....	3	25	9	16	1	1	....	....	....	....	56	+ 2
18	....	....	....	4	11	19	12	11	3	....	....	....	....	....	60	+ 3
19	....	....	....	....	5	14	12	10	1	4	....	....	....	....	46	+ 4
20	....	....	....	2	1	4	11	8	5	3	....	....	....	....	34	+ 5
21	....	....	....	1	1	8	7	14	3	1	1	....	....	....	36	+ 6
22	....	....	....	....	1	5	5	6	1	1	....	....	....	....	19	+ 7
23	....	....	....	....	1	5	1	7	3	1	2	3	....	....	23	+ 8
24	....	....	....	....	....	....	2	2	2	1	3	....	....	1	11	+ 9
25	....	....	....	....	....	2	1	3	....	1	....	....	....	....	7	+10
26	....	....	....	....	....	....	....	....	2	....	1	....	....	....	3	+11
27	....	....	....	....	....	2	....	....	....	....	....	....	....	....	2	+12
28	....	....	....	....	....	....	....	....	....	1	....	1	....	....	2	+13
29	....	....	....	....	....	....	....	1	....	....	....	1	....	....	2	+14
30	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0	+15
31	....	....	....	....	....	....	....	....	....	....	1	....	....	....	1	+16
32	....	....	....	....	....	....	....	....	....	....	....	1	....	....	1	+17
Frequency	4	19	64	117	171	258	132	122	27	19	9	6	0	1	949	
Departure from mean	—5	—4	—3	—2	—1	0	+1	+2	+3	+4	+5	+6	+7	+8	......	

Table XVI shows a comparison of height of the greenhouse seedlings in September, 1910, and in 1911. This table serves as another illustration of the opportunity of making selections on seedlings. Seventy-five per cent of the 1910 lot could have been discarded without losing any of the 10 best plants of 1911. A comparison of the correlation here shown, with the table presented by Clark [1] in his studies of timothy in 1910, shows that the conditions at Concord were more uniform than those at Ithaca.

One striking feature in connection with these studies is that the reliability of the height correlation is almost equaled by the reliability of height with next year's size (Table XV).

Data from mature plants in row A1 show a high correlation (Table XVII) between the amount of tops on the plants in the fall year by year and also a high correlation (Table XVIII) between the cut of individual plants compared in successive years.

[1] Clark, C. F. Bulletin 279, Cornell Agricultural Experiment Station. 1910.

TABLE XVI.—*Correlation between heights of the greenhouse seedlings of 1910 in 1910 and in 1911 (inches).*

[Height in 1910, subject; height in 1911, relative. Coefficient of correlation 0.642±0.0126.]

Height in 1910.	Height of plants in 1911 (inches).																												Frequency.	Departure from mean.
	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	81	84		
Inches:																														
4								1	1																				2	−11
5	1			2							2																		5	−10
6				1		2			1	2	5			1															12	− 9
7				2	1	1		1	1	6	6	4	3	1	2		1												29	− 8
8						1	2	1	3	6	2	6	1	6	1	2													31	− 7
9							1	5	8	6	8	11	4	7	5	1	1	2											59	− 6
10						2	3	1	4	6	7	3	11	5	5	1	2												50	− 5
11						1	2	2	6	10	5	12	9	17	3	3	3	3	2	1									79	− 4
12							1		4	10	8	7	11	9	5	6	2	4											67	− 3
13								2	2		7	14	5	17	10	8	3	7											75	− 2
14								1	3	4	6	5	12	15	9	6	9	11	2	2									85	− 1
15									1	1	2	7	14	9	14	14	4	8	5										79	0
16								1	1	2	3	3	8	9	10	8	13	10	2	1	2								73	+ 1
17										1	2	2	3	9	7	10	8	9	5										56	+ 2
18										1	3	3	2	10	9	12	8	6	3	3									60	+ 3
19											1	4	5	1	2	5	15	5	6	1	1								46	+ 4
20											1	2		3	2	4	7	5	4	3	3		1						34	+ 5
21											1	2		3	5	3	5	5	5	6		1							36	+ 6
22													1	2		2	5	4	1	1	2	1							19	+ 7
23													2	1	2	4	4	2	2	3	1	2							23	+ 8
24															1	2	1		2	3	1	1							11	+ 9
25																2	1	1	1	2									7	+10
26																			2	1									3	+11
27														1				1											2	+12
28																						1						1	2	+13
29																				1	1								2	+14
30																													0	+15
31																					1								1	+16
32																										1			1	+17
Frequency	1	0	0	5	1	7	9	15	35	55	69	84	91	126	92	93	92	83	42	28	12	6	1	0	0	1	0	1	949	
Departure from mean	−39	−36	−33	−30	−27	−24	−21	−18	−15	−12	− 9	− 6	− 3	0	+ 3	+ 6	+ 9	+12	+15	+18	+21	+24	+27	+30	+33	+36	+39	+42		

TABLE XVII.—*Correlation between area of cross section of fall stems of row A1 in 1910 and in 1911.*

[Stems in 1910, subject; stems in 1911, relative. Coefficient of correlation, 0.859±0.018.]

Stems in fall of 1910.	Area of cross section of stems in fall of 1911 (⅛-inch square units).																	Frequency.	Departure from mean.
	10	30	50	70	90	110	130	150	170	190	210	230	250	270	290	310	330		
⅛-inch square units:																			
10	8	9	1															18	− 2
30		5	6	4	2		1											18	− 1
50	2	1	3	4	2	2	1	1										16	0
70				1	3	1	4	4		1								14	+ 1
90							2	1			1							4	+ 2
110				1		1	1	1										4	+ 3
130						1			1	1								3	+ 4
150											1	1						2	+ 5
170																	1	1	+ 6
190																		0	+ 7
210																		0	+ 8
230																		0	+ 9
250																	1	1	+10
270																1		1	+11
Frequency	10	15	10	10	7	5	9	7	1	2	2	1	0	0	0	1	2	82	
Departure from mean	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+10	+11	+12	......	

TABLE XVIII.—*Correlation between the yield in 1910 and in 1911 from the plants in row A1, given in the sum of the squared diameters of the shoots from each hill.*

[Cut of 1911, subject; cut of 1910, relative. Coefficient of correlation, 0.797±0.027.]

Cut of 1911.	Cut of 1910 (square inches).											Frequency.	Departure from mean.
	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11		
Square inches:													
0 to 2	16	....	....	....	....	....	....	....	....	....	....	16	− 6
2 to 4	7	6	1	....	....	....	....	....	....	....	....	14	− 4
4 to 6	2	6	3	1	1	....	....	....	....	....	....	13	− 2
6 to 8	3	2	5	2	....	....	1	....	....	....	....	13	0
8 to 10	....	1	....	2	....	3	....	....	....	....	....	6	+ 2
10 to 12	....	....	3	1	4	1	....	....	....	....	....	9	+ 4
12 to 14	....	....	....	....	1	2	....	....	....	....	....	3	+ 6
14 to 16	....	....	....	1	1	....	....	....	....	....	....	2	+ 8
16 to 18	....	....	....	....	....	....	....	....	....	....	....	0	+10
18 to 20	....	....	....	....	....	2	....	....	1	....	....	3	+12
20 to 22	....	....	....	....	....	....	....	....	....	....	1	1	+14
22 to 24	....	....	....	....	....	....	....	....	1	....	....	1	+16
Frequency	28	15	12	7	7	8	1	0	2	0	1	81	
Departure from mean	−2	−1	0	+1	+2	+3	+4	+5	+6	+7	+8	......	

Table XIX shows how close a selection can be made for stalk diameter in 2-year-old plants by saving only the tall plants. This method, of course, is much quicker than to measure the diameter of the shoots of every plant in the bed.

TABLE XIX.—*Correlation between height (inches) and diameter of largest stalks ($\frac{1}{16}$-inch units) in 1911 of greenhouse seedlings of 1910.*

[Heights, subject; diameter, relative. Coefficient of correlation, 0.792±0.008.]

Height in 1911.	Diameter in 1911 ($\frac{1}{16}$-inch units).														Frequency.	Departure from mean.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
Inches:																
3	1	....	....	....	....	....	....	....	....	....	....	....	....	....	1	−39
6	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0	−36
9	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0	−33
12	3	2	....	....	....	....	....	....	....	....	....	....	....	....	5	−30
15	....	1	....	....	....	....	....	....	....	....	....	....	....	....	1	−27
18	....	4	3	....	....	....	....	....	....	....	....	....	....	....	7	−24
21	....	3	4	2	....	....	....	....	....	....	....	....	....	....	9	−21
24	....	5	6	4	....	....	....	....	....	....	....	....	....	....	15	−18
27	....	2	19	11	3	....	....	....	....	....	....	....	....	....	35	−15
30	....	2	13	27	8	5	....	....	....	....	....	....	....	....	55	−12
33	....	....	10	21	29	8	1	....	....	....	....	....	....	....	69	− 9
36	....	....	5	25	29	19	5	1	....	....	....	....	....	....	84	− 6
39	....	....	4	15	29	35	6	2	....	....	....	....	....	....	91	− 3
42	....	....	....	8	38	47	20	12	1	....	....	....	....	....	126	0
45	....	....	....	2	19	42	14	12	1	1	1	....	....	....	92	+ 3
48	....	....	....	1	11	41	19	17	2	....	1	1	....	....	93	+ 6
51	....	....	....	1	4	25	28	22	8	2	2	....	....	....	92	+ 9
54	....	....	....	....	1	29	23	24	2	4	....	....	....	....	83	+12
57	....	....	....	....	....	7	9	14	6	5	1	....	....	....	42	+15
60	....	....	....	....	....	....	4	14	4	3	2	1	....	....	28	+18
63	....	....	....	....	....	....	3	2	1	2	2	1	....	1	12	+21
66	....	....	....	....	....	....	....	2	1	2	....	1	....	....	6	+24
69	....	....	....	....	....	....	....	....	1	....	....	....	....	....	1	+27
72	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0	+30
75	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0	+33
78	....	....	....	....	....	....	....	....	....	....	....	1	....	....	1	+36
81	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0	+39
84	....	....	....	....	....	....	....	....	....	....	....	1	....	....	1	+42
Frequency	4	19	64	117	171	258	132	122	27	19	9	6	0	1	949	
Departure from mean	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	+7	+8	......	

All these tables go to show that in asparagus we are dealing with a stable plant with a permanent individuality; that an individual characteristic observed one year will persist in nearly unmodified form in future years. Without a study of this kind any breeding work would remain an uncertain proposition for several generations.

VIGOR OF SEEDLINGS OF MALE A7–83.

The several lots of hand-pollinated seed with the check lots of open-fertilized seed which were sown in the greenhouses at Washington in

FIG. 2.—Diagram showing the average height of 87 progeny rows of seedlings of 1910 in greenhouse. The measurements were made February 11, 1910, for comparison of open-fertilized and hand-pollinated lots of seed.

January, 1910, were planted to study the effect of the different parents on vigor of the young seedlings. These lots of seedlings varied markedly in average size, and it was easily seen that the open-fertilized lots of seed as a rule were shorter than the hand-pollinated lot from the same female plant. The accompanying diagram (fig. 2) shows the average heights on February 11 of the entire series of seedlings arranged in classes showing the different lots of hand-pollinated seed with the sample check from the same female. The check is shown in black with the different pedigreed lots following in outline. A study of the diagram shows that wherever male A7–83

was used an added vigor is shown in height over the check, which represents an average of the selected males. Of course, this check lot is influenced by the proximity of good or bad male plants, but usually several males would be about equidistant from any select female. Several other males show an added vigor, but the lack of rust resistance shown in these lots when exposed to rust in the fall of 1910 removes them from consideration. This difference of vigor is still maintained in the seedlings of 1910 after growing two years in the field. Of course, rust has entered into the effect now, but it certainly has not been the whole cause of the marked increase in the progeny of male A7–83.

The size of seed being so important a factor in seedling size, it was thought best to continue this study in 1911 on lots of seed of the same

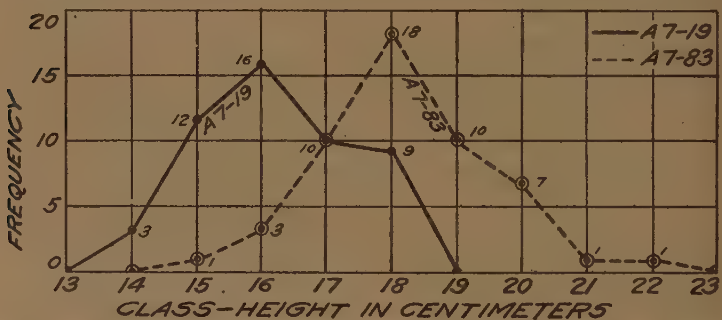

Fig. 3.—Diagram showing the height of 50 seedlings each from A7–25 pollinated with A7–19 (male) and A7–83 (male), seed weighing between 0.021 and 0.024 gram.

average size. Female plant A7–25 was pollinated with both male A7–83 and male A7–19 in the summer of 1910 and carefully weighed seeds of the two lots were planted to show the effect both of seed size and of vigor from the male. The effect of these two factors on the seedlings when 10 days old is shown in Table XX. To show the effect of A7–83 on seedling vigor, 50 seedlings from each lot representing the different males were selected from seed weighing as near as possible the same; in each case the weights ranged between 21 and 24 milligrams. In the diagram shown as figure 3 a comparison is made between the heights 10 days after germination of lots of seedlings from A7–25 pollinated with these two males. The result shows that the added vigor of the lot from A7–83 is due to something besides large seed.

TABLE XX.—*Comparison of weight of seed and height of seedlings at 10 days of age from two lots of 1910 seed from A7–25 female, the two lots having different male parents, A7–19 and A7–83.*

Weight of seed.		Height of seedlings (centimeters).												Weight frequency.	
		12	13	14	15	16	17	18	19	20	21	22	23	A7–19	A7–83
Milligrams:															
13	A7–19	1												1	
	A7–83														
14	A7–19			1										1	
	A7–83														
15	A7–19													0	
	A7–83														
16	A7–19		1											1	
	A7–83														
17	A7–19		1		2									3	
	A7–83														
18	A7–19				1									1	
	A7–83				1										1
19	A7–19			1	1	4	1							7	
	A7–83		1												1
20	A7–19			1	3	6	1							11	
	A7–83														0
21	A7–19				5	5	3	1						14	
	A7–83							5	1						6
22	A7–19			1	6	4	3	3						17	
	A7–83					1	4		1	2					8
23	A7–19					5	4	4						13	
	A7–83				1	1	3	7	4	2					18
24	A7–19			2	1	2		1						6	
	A7–83					1	4	10	5	3	1	1			24
25	A7–19						1	5	4					10	
	A7–83		1			2	2	5	4	4	1				19
26	A7–19						1		2	2				5	
	A7–83							2	2	2	2	2	1		11
27	A7–19				1			3						4	
	A7–83									1	1				2
28	A7–19								1		1			2	
	A7–83									1	1		2		4
29	A7–19														
	A7–83											1	1		2
30	A7–19														
	A7–83											1			1
Height frequency:	A7–19	1	2	6	20	26	14	17	7	2	1			96	
	A7–83		2	0	2	5	13	29	17	15	6	5	4		97

RUST RESISTANCE.

To any one familiar with rusty asparagus fields the injury caused by rust is apparent, yet the actual damage is hard to estimate on account of the different seasons affecting the cut of the crop.

Table XXI shows the relation between the percentage of stem cross section of the crop of 1911 to that of 1909 and the rust resistance of 1910. Several plants growing in 1909 rusted so badly that they died before 1911, and are therefore excluded from the table. It is realized that the increase in size of asparagus hills is influenced by many things other than rust, so that the actual effect of rust is much higher than the coefficient given shows.

TABLE XXI.—*Correlation between the degree of rust resistance in 1910 and the percentage of the stem cross section of 1911 to that of 1909 in row A1.*

Rust resistance, subject; percentage of stem cross section, relative. Coefficient of correlation 0.393±0.065.]

Rust resistance in 1910.	Percentage of stem cross section of 1911 to that of 1909.														Frequency.	Departure from mean.
	20	60	100	140	180	220	260	300	340	380	420	460	500	540		
Grade:																
0	....	6	2	2	1	....	....	....	....	....	....	....	....	....	11	−4
1	1	2	2	3	....	....	1	....	....	....	....	....	....	....	9	−3
2	....	2	....	3	2	1	....	....	....	....	....	....	....	....	8	−2
3	1	1	....	2	3	1	1	....	....	1	....	....	....	....	10	−1
4	....	....	1	3	1	....	1	....	....	....	....	....	....	....	6	0
5	....	3	1	....	1	3	....	....	....	1	....	....	....	1	10	+1
6	1	1	3	....	2	1	2	....	....	....	....	....	....	....	10	+2
7	....	....	1	2	1	....	....	....	....	....	1	....	....	1	6	+3
8	....	....	....	1	3	....	3	1	....	....	....	....	....	....	8	+4
Frequency	3	15	10	16	14	6	8	1	0	2	1	0	0	2	78	......
Departure from mean	−160	−120	−80	−40	0	+40	+80	+120	+160	+200	+240	+280	+320	+360	....	......

In 1910 a study was made of the rust resistance of the seedlings started in the greenhouse at Washington and later transferred to a permanent place in the field at Concord. The rust attacked the field in August, so that in the latter part of September some of the nonresistant plants were dead. The seedlings of the several lots were then judged as individuals, and Table XXII shows how they ranked in rust resistance. Lots 1, 4, 8, 11, etc., are from open-fertilized seed from the female plants used, while lots 2, 3, 5, 6, etc., are from seed hand pollinated from male plants mentioned in the second column of the table. A study of the table shows A7–83 to be possessed of great power to transmit rust resistance. The results shown in this table are those on which our breeding work is now based. A7–35 is the only other male showing desirable resistance. This male is being tested further and may be selected as a breeding plant. But there is now no question as to the desirability of A7–83 (Pl. X, figs. 1, 2, and 3, and Pl. XI).

TABLE XXII.—*Rust resistance of individual greenhouse seedlings of 1910 in progeny lots in the field, September, 1910.*

Parent plants. ♀	Parent plants. ×♂	No.	Individual rust resistance of seedlings (grades). 0	1		2		3		4		5		6		7		8		9		10	Number of plants.	Mean.
A3-61	....	1	..	..	..	..	..	1	..	1	..	...	..	1	1	2	..	3	..	..	..	..	9	6.25
	A7-83	2	..	..	..	..	..	...	..	..	..	...	..	...	..	2	..	5	1	1	5	..	14	8.50
	B72-85	3	..	..	..	2	..	1	..	..	..	4	..	2	..	4	2	..	..	..	..	..	15	5.47
A3-73	....	4	..	..	..	..	..	2	..	..	..	2	1	2	..	3	..	..	..	..	..	..	10	5.45
	A7-19	5	..	..	..	..	..	...	..	2	..	4	..	1	..	3	..	..	..	..	..	..	10	5.50
	A7-83	6	..	..	..	..	..	...	..	1	..	...	..	1	..	1	1	2	2	1	..	..	9	7.39
	A7-85	7	..	..	..	..	..	...	..	2	1	4	..	1	1	...	..	1	..	..	..	..	10	5.30
A4-24	....	8	..	..	..	..	..	...	..	1	2	4	..	2	..	1	..	..	..	..	..	..	10	5.00
	A4-23	9	..	..	..	..	..	...	..	..	..	1	3	3	..	1	..	1	..	1	..	..	10	6.35
	A7-19	10	..	..	..	..	..	...	..	..	..	2	2	1	2	4	..	4	..	..	..	..	15	6.67
A4-62	....	11	..	..	..	..	..	1	..	3	1	2	1	...	1	1	..	1	..	..	..	..	11	5.74
	A7-83	12	..	..	..	..	..	...	..	..	..	...	1	...	..	1	..	1	3	2	1	..	9	8.19
	A7-85	13	..	..	..	..	..	...	..	..	1	1	1	3	..	2	1	1	..	..	..	..	10	6.25

PLANT "WASHINGTON," A7-83, SHOWING THE GENERAL TYPE OF THE BEST BREEDING MALE USED IN THE RUST-RESISTANT BREEDING WORK.

(Photograph taken June, 1910.)

PLANT "MARTHA," B32-39, SHOWING THE GENERAL TYPE OF THE BEST BREEDING FEMALE USED IN THE RUST-RESISTANT BREEDING WORK.

(Photograph taken September, 1909.)

TABLE XXII.—*Rust resistance of individual greenhouse seedlings of 1910 in progeny lots in the field, September, 1910*—Continued.

Parent plants. ♀	Parent plants. ×♂	No.	0	1		2		3		4		5		6		7		8		9		10	Number of plants.	Mean.
A7-25		14								1	1	1	2	2	1	2							10	5.70
	A7-19	15										2	3	3		4	1	2					15	6.07
	B24-13	16				5		4				1											10	2.70
A8-9		17						1		1	1	1		3		1							8	5.19
	A7-7	18						1			2			3		1							7	5.29
	A7-19	19								1	2	6	1	4		4							18	5.58
	B12-1	20						1		1		3		1	1	3							10	5.55
	B24-13	21		3		4		3															10	2.00
B32-39		22								1	1	2	1	1		2			2				10	6.10
	A7-19	23									1		1	3	2	6	4	1	1				19	6.82
	A7-19	24								1	1	1	1	4	1	3	2	1					15	6.23
	A7-83	25																		1	6	1	8	9.50
	W-2	26									1	1			4	1	2						9	6.39
B70-14		27									1	5	3					1					10	5.40
	B98-32	28								1	1	2	2	1	2								9	5.39
B84-14		29						2	1	1		2	2			1	1						10	4.90
	B12-1	30									2	2	1	1	1	1	1	1					10	5.95
	B88-63	31						1				3	1	3		3							11	5.68
	B90-10	32				1		2		3		2		2									10	4.20
	B114-31	33					1	5	2		1					1							10	3.60
B84-44		34				1				3		1	3	1		1							10	4.85
	A7-19	35								1	1	1	1	3			2						9	5.78
	A7-19	36													1	3	1	4	1				10	7.55
	A7-83	37															1	6	2				9	8.05
	B98-32	38				1		1	1	2	2	2		1									10	4.15
	B98-44	39						1	1			3	2	1		2							10	5.25
	C7-5-12	40							5			2		2		1							10	4.65
	C13-5-33	41								2		2	1	2	1		1						9	5.50
	W-1	42								1				5	1	2							9	6.06
B84-47		43				1		2	1	3			1	2									10	4.10
	C7-5-12	44					1	2	4					2	1								10	4.10
	W-1	45						1			3	3		5	1		1						14	5.39
B84-69		46				1		3	1	1			1		1								8	3.81
	A7-83	47						1		2		3		3		2	1	2	1				15	6.00
	B88-70	48						2	2	2	1	3											10	4.05
B92-43		49				2		3	2			1		2									10	3.70
	A7-19	50						1	2	3	1	2		2		1	1	1					14	5.07
	B98-48	51		1		1	1	2		2	1			1		1							10	3.70
	B114-31	52								1	1	3	2	1		2							10	5.45
B114-51		53								1		1		1	2	3	1	2					11	6.77
	B98-32	54									4		1	1		2							8	5.44
B132-26		55								1		2		3		4							10	6.00
	A7-83	56														2	1	2	4	1			10	8.05
	B88-63	57						1		1		1		2	1	4							10	5.85
B136-4		58				1		2						3		2	1						9	5.28
	A7-35	59														1	1	3	2	3			10	8.25
	W-1	60								1		2	1	1		4	1						11	5.96
	W-2	61		1				5		2	1	1											10	3.35
B136-24		62						1		2		2		2		2	1						10	5.45
	C8-2-45	63				1		2		2		4		1									10	4.20
B140-25		64						2				5		2	1								10	4.95
	C7-5-12	65						1	1	1		1		6									10	5.15
	C13-5-33	66					1		2	1		4	1										9	4.33
B144-16		67						2	1	2		2		2		1							10	4.35
	A7-19	68				1		1	2	4		1		1									10	3.90
	C7-5-12	69		2		3		1	1	2		1											10	2.75
	C13-5-33	70				1	2	2		2	1	2		1									11	3.77
	C17-1-23	71				1	1	4		2		2											10	3.45
	W-2	72	1	3	1	1	1	1		2													10	2.00
C6-3-14		73				2	1	7															10	2.75
	A7-19	74					1	1	1	1		4		1									9	4.33
	C7-5-12	75		1		1		3	1	1		2		1									10	3.55
C6-3-31		76						1			2	4	1			1							9	4.94
	A7-83	77										1				2	4	2	1				10	7.35
	W-1	78						1		1		1		3		1	1	2					10	6.05
C13-5-1		79				1					1	3		2		1	1						9	5.33
	A7-85	80						2	2	1	1	3	2	4		3		2					20	5.43
	C13-5-33	81					1	2	4	3	1	3											14	3.86
	W-1	82					1	2	3	1	3	6		1		1	1						19	4.58
C19-3-44		83		1			1	3	1	3		1											10	3.30
	A7-19	84								3		4	2	6									15	5.27
	A7-85	85		1			1	3	3	2		6		2		1							19	4.21
C21-5-33		86	1			1	1	1		1	1	1		3									10	3.90
	A7-85	87								1		6				3							10	5.50
	C21-5-47	89					1	6		3													10	3.25
	Total	....	2	13	1	33	16	101	44	93	47	160	46	130	27	111	36	51	20	10	12	1	951	......

Table XXIII shows the height of these greenhouse seedlings at the end of the season's growth in 1910. Again A7–83 is found standing out above the other males in the transmission of vigor. As mentioned on page 44, in respect to the vigor of seedlings of some of the males while in the greenhouse, some good lots are found, but they are poor in rust resistance, and the male parents have been discarded.

TABLE XXIII.—*Height of individual greenhouse seedlings of 1910, in progeny lots in the field, September, 1910.*

Parent plants.		Row No.	Height in inches.																														Number of plants.	Mean height.
♀	×♂		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32		
A3-61		1								2	3	1		3	1																		10	12.20
	A7-83	2									2			2	1	2	2	1	2				1		1								14	16.79
	A7-85	3					1				1	1	1		1	3		3	2	1		1											15	16.00
A3-73		4					1				1		5	1	1					1													10	13.20
	A7-19	5						2	2	1	2						1				2												10	12.50
	A7-83	6					1		1			1		1	1	2		1									1						9	14.89
	A7-85	7			1	1		1			1	2		2				1			1												10	12.10
A4-73		8					1		1		1	2	1	3	1																		10	12.10
	A4-23	9									1		1	3	1	1	1	1	1														10	15.10
	A7-19	10			1							1		1	3	1	2	3	2			1											15	16.00
A4-62		11							1	1		1	1		1		2	1	1		2												11	15.64
	A7-83	12									1			1	1	1			1	1		1		1	1								9	18.44
	A7-85	13												1	1	1		4			2	1											10	18.10
A7-25		14									2	1	1	1	2	1		1	1														10	14.40
	A7-19	15					1		1	3	1	2	3	3					1														15	12.07
	B24-13	16				1	1	2	3	1		1		1																			10	9.20
A8- 9		17							2		2		1	1	1	1																	8	12.25
	A7- 7	18						2	1	1		2			1																		7	10.57
	A7-19	19			1		3	2	7	2	2		1																				18	8.89
	B12- 1	20			1		1		2	1	1	3	1																				10	10.00
	B24-13	21		1	1	2		2	1		2		1																				10	8.10
B32-39		22									1		1	1	2	2	3																10	15.10
	A7-19	23							1	1		3	1	3	2		3	2		2		1											19	15.21
	A7-19	24							1	2	2	2	3	2	1		1	1															15	12.80
	A7-83	25				1		2				1	1	1	1		1																8	11.63
	W- 2	26					1				1		1	2	1	1	1				1												9	14.22
B70-14		27	1					1			2	1	2	1	1					1													10	12.00
	B98-32	28				1	1		1		1	2			2			1															9	9.17
B84-14		29					1	1								2		1	2	1		2											10	16.70
	B12- 1	30										1	1	2	2		1	2			1												10	14.90
	B88-63	31							1				1	2		1				2	2	1							1				11	18.09
	B90-10	32									2	2	1		1	1		1	1				1										10	15.00
	B114-31	33							1	2	1	1		1		2							1				1						10	14.80
B84-44		34								1			1				2	2		1	1		1		1								10	18.20
	A7-19	35										1			1				2	1	1		2		1								9	19.67
	A7-19	36												1				1	1	1	3	1	1	1									10	20.30
	A7-83	37													1		1		1	1	1	1	2					1					9	20.44
	B98-32	38					1		1				2		2	2			1					1									10	14.70
	B98-44	39								1				1		3			2	1	1		1										10	17.40
	C7-5-12	40									2			2	1	2		1		1	1												10	15.60
	C13-5-33	41								1	2		1			1		2		1	1												9	15.33
	W- 1	42										1	2	1			1	1	1			1	1										9	16.78
B84-47		43					1			1				3	1		1	1	1										1				10	15.70
	C7-5-12	44						1		1	1				1	3	2	1															10	14.40
	W- 1	45											1	3	2	1	2	3	1	1													14	16.29
B84-69		46				1				3	2						1	1															8	11.63
	A7-83	47						2	3		3	1		3	2						1												15	12.07
	B88-70	48					1	3	2	2	1			1																			10	9.40
B92-43		49							2		2	1	2	1		1		1															10	12.60
	A7-19	50					1	1	2	3	2	2			2	1																	14	11.07
	B98-48	51									1		1	2	2	2		2															10	15.00
	B114-31	52				1			1			2		2	1		1	2															10	13.50
B114-51		53							1	2	1	3	1	1		1	1																11	12.36
	B98-32	54								1	1	3		1	1	1																	8	11.25
B132-26		55											1		4	1	1			1	1	1											10	16.90
	A7-83	56													1	1			2				3	1	1	1							10	21.30
	B88-63	57										1	1		2			2			2	1	1										10	17.80

Table XXIII.—*Height of individual greenhouse seedlings of 1910, in progeny lots in the field, September, 1910*—Continued.

Parent plants. ♀	Parent plants. ×♂	Row No.	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Number of plants.	Mean height.
B136-4	....	58	..	..	1	..	..	1	..	1	..	..	..	..	1	2	1	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	9	13.78
	A7-35	59	..	..	..	..	..	..	..	..	..	..	..	..	..	2	1	..	1	3	3	..	..	..	..	..	..	..	..	..	..	..	10	19.10
	W-1	60	..	1	..	..	1	..	1	1	..	..	..	3	1	2	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	11	12.36
	W-2	61	..	..	..	1	..	..	..	..	3	1	2	2	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	12.10
B136-24	....	62	..	..	..	..	..	..	1	1	..	..	1	..	1	5	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	14.40
	C8-2-45	63	..	..	..	..	..	..	..	..	1	1	1	..	4	..	..	1	1	1	..	..	..	..	..	..	..	..	..	..	..	..	10	15.30
B140-25	....	64	..	..	..	..	..	..	..	..	..	..	1	..	..	1	2	2	1	..	..	..	1	2	..	..	..	..	..	..	..	..	10	18.90
	C7-5-12	65	..	..	..	..	..	..	..	..	..	1	..	..	..	1	1	..	..	2	..	..	1	1	..	1	..	1	..	..	..	1	10	21.80
	C13-5-33	66	..	..	..	..	..	..	..	..	..	..	2	2	3	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9	14.56
B144-16	....	67	..	..	..	..	..	..	..	..	2	1	1	..	1	1	..	..	1	..	2	..	..	1	..	..	..	..	..	..	..	..	10	16.30
	A7-19	68	..	..	..	..	1	..	..	..	..	2	2	1	1	..	2	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	10	14.10
	C7-5-12	69	..	..	..	..	..	2	1	..	1	1	1	2	..	..	1	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	10	12.50
	C13-5-33	70	..	..	..	..	2	..	..	2	2	1	2	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	11	11.18
	C17-1-23	71	..	..	..	1	1	1	3	..	..	..	1	2	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	10.20
	W-2	72	..	..	..	..	3	1	1	..	3	1	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	10.00
C6-3-14	....	73	..	..	..	..	1	1	2	2	2	..	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	10.20
	A7-19	74	..	..	..	..	1	1	4	1	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9	9.33
	C7-5-12	75	..	..	..	..	..	1	..	..	..	2	..	1	1	..	4	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	14.70
C6-3-31	....	76	..	..	..	..	..	..	..	1	..	1	..	2	1	1	..	..	1	2	..	..	..	..	..	..	..	..	..	..	..	..	9	15.56
	A7-83	77	..	..	..	..	..	..	..	..	..	..	..	1	1	2	..	1	1	..	..	2	2	..	..	..	..	..	..	..	..	..	10	18.80
	W-1	78	..	..	..	..	..	..	..	..	1	..	2	..	..	1	1	1	..	1	1	..	2	..	..	..	..	..	..	..	..	..	10	17.50
C13-5-1	....	79	..	..	..	..	..	..	..	3	..	1	1	..	1	2	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9	13.22
	A7-85	80	..	..	..	..	..	..	..	..	1	..	..	2	..	1	1	2	5	4	..	1	1	2	..	..	..	..	..	..	..	..	20	18.80
	C13-5-33	81	..	..	..	..	..	1	1	..	2	..	1	2	..	2	1	3	1	..	..	..	..	..	..	..	..	..	..	..	..	..	14	14.43
	W-1	82	..	..	..	..	..	..	..	..	1	..	1	..	[illegible]	..	2	1	2	..	3	1	1	1	2	1	..	..	..	..	1	..	19	20.16
C19-3-44	....	83	..	1	1	..	1	1	..	1	1	2	..	1	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	10.10
	A7-19	84	..	2	1	..	..	1	..	..	2	..	3	..	[illegible]	..	1	..	..	1	..	..	1	..	..	..	..	..	..	..	..	..	15	12.47
	A7-85	85	..	..	1	..	..	..	3	1	1	2	5	..	..	1	2	1	1	1	..	..	..	..	..	..	..	..	..	..	..	..	19	13.11
C21-5-33	....	86	..	..	..	..	1	..	1	..	..	1	3	..	..	1	..	2	..	1	..	..	..	..	..	..	..	..	..	..	..	..	10	13.90
	A7-85	87	..	..	..	..	..	..	1	..	..	..	1	..	1	1	2	..	2	1	..	1	..	..	..	..	..	..	..	..	..	..	10	16.70
	C21-5-47	89	..	..	..	2	..	..	..	3	..	1	1	..	1	1	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	10	12.00
Total.........		..	1	5	9	12	29	33	58	50	75	66	75	84	79	72	57	61	45	35	34	19	24	11	7	3	2	2	2	..	1	1	952	14.42

Among the females, B32–39 (Pl. XII) stands out in the 1910 test as a good parent for rust resistance. Unfortunately the progeny lot of seedlings B32–39×A7–83 was in poor ground and did not show well in vigor compared to the open-fertilized lot which was in normal soil at the other end of the field. As was found in 1911, this apparent lack of vigor was due to poor ground only.

The accompanying diagram (fig. 4) shows a comparison between A7–83 and A7–19, the two males used most in our pollination work in 1909, both in rust resistance and vigor transmission on the various lots of progeny from different females. Accompanying the records for each progeny is that of the check lot open-fertilized from the same females. This table shows strikingly the great advantage in using pedigreed seed of good parents. Attention is again called to the fact that the male plants available for pollination of the open-pollinated seed were, with few exceptions, select plants.

PERMANENCY OF RUST RESISTANCE.

A study of rust resistance year by year shows the same permanence of this character in the plants that was shown in the studies of size,

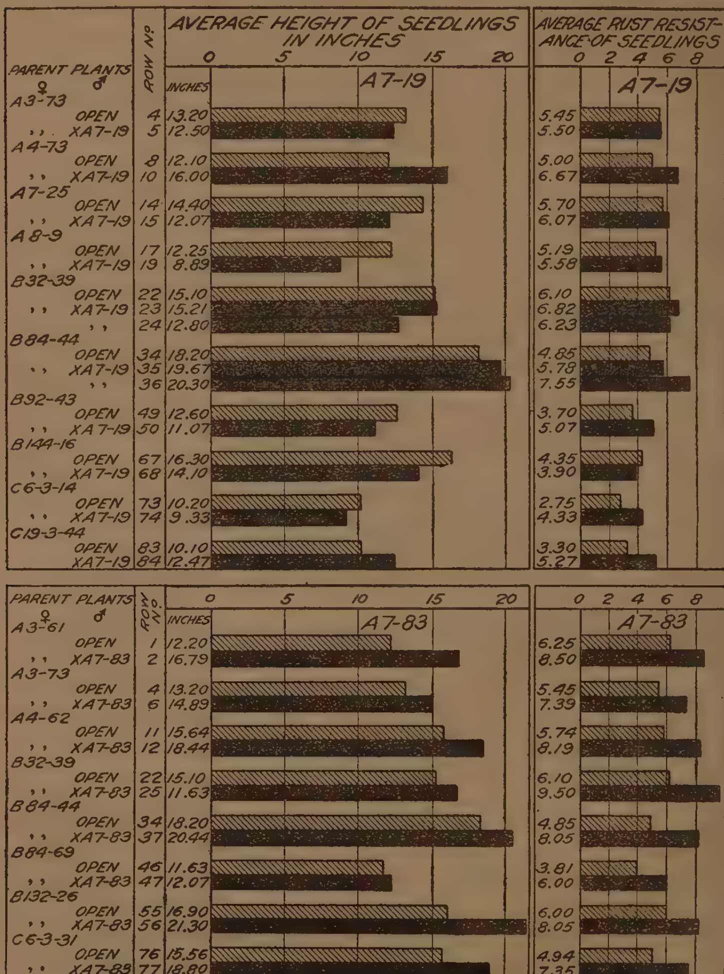

FIG. 4.—Diagram showing the effect on greenhouse seedlings of 1910 of A7-19 and A7-83 with respect to the average heights and average rust resistance of progeny lots in comparison with the progeny from open-fertilized seed from the same female plants.

yield, etc. Once the individual plants are learned, their individuality is recognized in different seasons. The attack of rust on the greenhouse seedlings in 1910 was very uniform and satisfactory from the

standpoint of selection of rust-resistant plants. In 1911 the rust came on very much later and did not get started uniformly over the plat. Some lots were attacked as badly as in 1910, but the ends and outside rows where exposed to the wind and plants that were shaded by trees failed to show as much rust as in 1910. In spite of this fact, the correlation between the rust resistance for the two seasons of the individuals included in the tests of both years is quite high (Table XXIV).

TABLE XXIV.—*Correlation between rust resistance in 1910 and in 1911 of greenhouse seedlings of 1910.*

[Resistance in 1910, subject; resistance in 1911, relative. Coefficient of correlation 0.512±0.015.]

Resistance in 1910.	Rust resistance in 1911 (grades).											Frequency.	Departure from mean.
	0	1	2	3	4	5	6	7	8	9	10		
Grades:													
0	......	......	......	......	......	......	......	1	1	......	......	2	−5
1	......	3	1	1	......	1	2	4	......	......	......	12	−4
2	1	3	1	5	5	6	1	12	2	......	......	36	−3
3	......	1	2	7	5	13	13	34	34	10	......	119	−2
4	......	......	......	3	5	7	12	47	38	23	3	138	−1
5	......	......	1	2	1	15	22	40	74	40	13	208	0
6	......	......	1	......	3	5	13	32	60	39	22	175	+1
7	......	......	......	......	......	3	5	20	52	39	19	138	+2
8	......	......	......	......	......	......	1	9	19	29	26	84	+3
9	......	......	......	......	......	......	......	......	4	9	14	27	+4
10	......	......	......	......	......	......	......	......	1	3	2	6	+5
Frequency	1	7	6	18	19	50	69	199	285	192	99	945	
Departure from mean	−8	−7	−6	−5	−4	−3	−2	−1	0	+1	+2	......	

It should be noted that very few plants show greater rust in 1911 than in 1910. If the rust attacks had been of equal severity both seasons, a much higher value for the coefficient of correlation would have been obtained.

As was shown in Table XXI, there is a definite relation between increase in size and rust resistance. The young seedlings in the greenhouse lot show a relation between rust resistance and size, but to a certain extent the size is dependent even yet on the size of the seed. In Table XXV the heights in September, 1911, are correlated with the rust resistance of plants as observed in September, 1910. The first 25 lots of the greenhouse seedlings were used in this table, as the rust attack in 1911 on this row was more uniform than on the other rows.

TABLE XXV.—*Correlation between height in 1911 (inches) and rust resistance in 1910, row 1 of greenhouse seedlings of 1910.*

[Height in 1911, subject; rust resistance in 1910, relative. Coefficient of correlation 0.484±0.032.]

Height in 1911.	Rust resistance in 1910 (grades).										Frequency.	Departure from mean.
	1	2	3	4	5	6	7	8	9	10		
Inches:												
12					1						1	—9
15						1					1	—8
18		1		1		1					3	—7
21	1			1	3			1			6	—6
24		1	1			2					4	—5
27		3	2	2	6	5					18	—4
30		1	5	5	7	7	2	2			29	—3
33		2	2	2	9	5	8	3	2	2	34	—2
36	2	1	1	3	8	11	8	4			38	—1
39		3	1		7	11	12	8	1		43	0
42			1	1	7	6	13	3		1	32	+1
45					1	5	9	3	2		20	+2
48				1	3	2	3	4	3	1	17	+3
51			1		2	4	1	2	3	3	16	+4
54							4	1	1		6	+5
57										1	1	+6
60							1	1	1		3	+7
63									1		1	+8
Frequency	3	12	14	16	54	60	61	32	14	7	273	
Departure from mean	—5	—4	—3	—2	—1	0	+1	+2	+3	+4		

SEEDLINGS OF 1911.

In 1910 the work of making pedigree combinations was continued in the spring months. This work was done before the rust developed and was naturally of a more or less hit-or-miss character. Male plants were selected for their individual qualities with the hope that they would transmit these qualities to their offspring. A7–19 and A7–83 were used as check males to test new female plants. The female plants that had given the best resistance both in 1908 and in 1909 were also used in making combinations with these males with the plan that if any of the 1909 combinations showed desirable resistance the 1910 lots of seed would furnish an additional supply of the desirable progeny.

The seed resulting from these pollinations was planted in 1911 at Concord, and when the rust attack developed in August the behavior of the different progenies was much the same as in 1910. A7–19 proved to be a failure in point of transmission of rust resistance and has been discarded. A7–83, however, again performed in a very satisfactory manner. Its progeny proved highly resistant to rust and very vigorous in comparison with seedlings from American stock lacking in rust resistance. Plate XIII shows a row of seedlings from plants in row B24 (fig. 1) compared with the best resistant progeny "Martha Washington" (fig. 2). The striking difference in the two photographs is not so great as the contrast in the field, where the rich green of "Martha Washington" contrasts with the gray brown of the dead seedlings from row B24.

FIG. 1.—WAKEMAN SEEDLING STOCK, SHOWING TOPS ENTIRELY KILLED BY RUST.

(Photograph taken September 25, 1911.)

FIG. 2.—"MARTHA WASHINGTON" STOCK (PROGENY B32-39 × A7-83), COMMERCIALLY IMMUNE PLANTS OF STRONG VIGOR.

(Photograph taken September 25, 1911.)

PEDIGREE SEEDLINGS OF 1911 AFTER A SEVERE ATTACK OF RUST.

PEDIGREE SEEDLINGS OF 1911 AFTER A SEVERE ATTACK OF RUST, SHOWING VARIABLE RESISTANCE OF STANDARD GIANT ARGENTEUIL, ALL PLANTS SUFFERING FROM RUST.

(Photograph taken September 25, 1911.)

PEDIGREE SEEDLINGS OF 1911 AFTER A SEVERE ATTACK OF RUST, SHOWING PLANTS FROM STANDARD READING GIANT SEED, SOME NEARLY IMMUNE, OTHERS RUSTY.

(Photograph taken September 25, 1911.)

PEDIGREE SEEDLINGS OF 1911 AFTER A SEVERE ATTACK OF RUST, SHOWING THE EFFECT OF CROSSING A7-83 ON A FEMALE PLANT (A2-23) OF AVERAGE RESISTANCE.

(Photograph taken September 25, 1911.)

PEDIGREE SEEDLINGS OF 1911 AFTER A SEVERE ATTACK OF RUST, SHOWING PLANTS FROM OPEN-FERTILIZED SEED OF B32-39, USUALLY QUITE RESISTANT BUT LACKING IN VIGOR.

(Photograph taken September 25, 1911.)

FIG. 1.—SEEDLINGS AT THE SOUTH END OF A BED AT CONCORD, MASS., IN AUGUST, 1910, JUST BEGINNING TO RUST.

FIG. 2.—SEEDLINGS AT THE NORTH END OF THE BED SHOWN IN FIGURE 1 ON THE SAME DAY, SHOWING THE DESTRUCTION OF PLANTS CAUSED BY THEIR PROXIMITY TO A YOUNG BED ON WHICH CLUSTER CUPS DEVELOPED ABUNDANTLY.

EFFECT OF RUST ON ASPARAGUS SEEDLINGS.

Photographs do not show the dead color of plants injured by rust, but in Plate XIV the effect of the 1911 rust attack is shown on American-grown Argenteuil stock, and Plate XV shows American-grown Reading Giant stock in an adjoining row. There is no question that Reading Giant contains plants of greater resistance than any to be found in any lot of Argenteuil grown on the station grounds at Concord. Plates XIV and XV show this difference about as it occurs in the regular field growth of the two stocks. The seedlings from A7–83 progenies are superior to these standard strains in both rust resistance and vigor (Pl. XVI). B32–39 gives very resistant seedlings even when open fertilized with males of medium resistance (Pl. XVII). The small size of the seeds of this plant places the seedlings at a disadvantage, and the combination with A7–83 is needed to give vigor.

In the tests of 1911 no new progeny lots showed a resistance or vigor comparable with that of "Martha Washington." Most of the plants tested will be discarded, a few females being held for a further test. New selections from Reading Giant and from A7–83 progeny are included in the pollination work in 1912. Some of these new selections show such a high individual resistance that it is practically certain that some of the new combinations with A7–83 will show great resistance.

BUD PROPAGATION.

In order to increase the product of seed from individual plants it will be necessary to carry out some methods of vegetative propagation. Preliminary experiments to this end were undertaken in the greenhouse in 1910. Seedlings planted January, 1910, were separated when they had several shoots; the roots were divided more or less evenly and the plants repotted. Nearly all of them grew, and in about a month they were separated again. This was kept up until in January, 1911, two seedling plants were represented by 60 or more plants. When properly handled few plants die. In the fall of 1910 about half the crowns of No. 1 Washington, No. 2 Martha, B32–4, and A2–23 were dug up, shipped to Washington, and planted in the greenhouse. These crowns were split into several smaller clusters and planted in 12-inch pots. New shoots started, but on account of low temperature did not completely develop, and finally died back. When the pots were moved into a warmer house the divided crowns started growing again, and some of the plants have been divided a second time. This method of vegetative propagation will be necessary in breeding and seed-growing work.

PEDIGREE.

In pedigree breeding work the performance of the parent individuals is not important in itself, and is only of value as it shows the ability of the plant to transmit its good qualities to its offspring.

These plants selected for breeding purposes become valuable only as their progeny show uniformly high quality and yield. So when a pedigreed progeny shows a high commercial value its parent plants become of great importance. They should be increased as fast as possible by clonal propagation and should be isolated and allowed to produce as much seed as possible. It is now that records and history become important. Careful record should be kept of their original source, etc., and future development.

In carrying out the work on this breeding project and of private breeding work developing from it the following scheme will be used:

Number.—Each plant that proves of value as a breeding parent will be assigned a permanent serial number. These numbers will not be given to a plant until its progeny show it to be of value as a breeding parent. Its preliminary records will be kept under a temporary number used to mark its location in the testing plat.

Name.—Plants used to produce progenies for commercial planting will be given names as follows: The male plants will be given surnames as Washington, Wilson, Prescott, Wheeler, Moore, etc., the name assigned to one plant not to be duplicated in the future. Female plants will be named by assigning them different feminine names, as Martha, Mary, Edith, etc.

Progenies will take their commercial or trade names from the two parents. Thus the progeny of No. 2 Martha × No. 1 Washington will be known to the trade and growers as "Martha Washington"; No. 3 Edith × No. 1 Washington would be "Edith Washington"; No. 2 Martha × No. 4 Wheeler would be "Martha Wheeler." In this way each progeny would by its name indicate its parents.

Records.—In keeping pedigree records the loose-leaf record book will be used. A primary sheet for each parent admitted to registry will be used, giving its history, description, etc. The performance of the plants as shown by their progeny records will be filed under the female parent as secondary sheets. An abbreviated record of these progeny sheets will be filed under the male parents as secondary sheets to show the performance.

No. 1. Washington ♂.

Pedigree: ♀ unknown.
♂ unknown.

History: Original plant found in 1908, location A7–83. New American Concord-grown stock by Anson Wheeler. Marked as best male in type and rust resistance. Used in 1909 and 1910 in crossing work. In 1911 used as test male in all crossing work.

Progeny: Very resistant to rust and showing an added vigor above open-fertilized progeny no matter what female parent was used.

Propagation: Part of original parent dug up in 1910 for clonal propagation.

No. 2. Martha ♀.

Pedigree: ♀ unknown.
♂ unknown.

History: Original plant found in 1908, location B32–39. Reading Giant stock. Marked as best in rust resistance 1909; rather small type; used in 1909 and 1910 in crossing work. In 1911, under cage, crossed with No. 1.

Progeny: Open-fertilized lots of 1909 and 1910 better in resistance than any other open-fertilized lots tested. × No. 1 progeny best for resistance and type of any seedlings grown.

Propagation: Part of original parent dug up in 1910 for clonal propagation.

When plants from any named progeny develop as good breeding parents they will be assigned new names and handled as distinct parents, their history and pedigree being recorded on their original pedigree sheets.

When by vegetative propagation the original parent plants have increased so that different growers have lots of the same progeny, in offering them for sale the grower's name should accompany the progeny name for purposes of identification in case any error creeps in; as, Martha Washington (Frank Wheeler stock), Martha Washington (C. W. Prescott stock). The registry of new parents for breeding purposes should be through a central breeding organization, so that no duplication of names will occur. For the present this work can be done at the experimental station at Concord. These new progeny lots must be tested in competition with some standard progeny of known rust resistance and quality and their general value determined.

PLANS FOR DISTRIBUTION.

When sufficient stock of any progeny is obtained to warrant distribution to interested growers, plans will be made to plant the stock under conditions favorable to the satisfactory testing of these progenies for resistance to rust. The lots of seed or seedlings issued by the Department will, as far as possible, be sent to growers who will be in a position to aid in extending the cultivation of the rust-resistant strains.

SUGGESTIONS TO BREEDERS AND GROWERS.

In giving advice in regard to asparagus breeding at this time it must be remembered that our experiments are only just begun. Later results are liable to change the methods of procedure to be recommended, but the methods and practices at present followed are here outlined.

RUST RESISTANCE.

If rust is a factor in the region where the work is to be done, resistant varieties are of prime importance. In order to secure resistant selections rust must be present in abundance. Unless one can pick

the one superior plant out of a thousand in point of rust resistance the work will be hard.

Late fall is the best time for making field selections, because at that season the rust will be developed sufficiently to have marked the nonresistant plants in the field so that they can be disregarded.

In providing rust for this work in New England it will usually be sufficient to leave an area of nonresistant plants in one corner of the field, preferably that from which the prevailing winds come. If there was plenty of black rust the preceding season, the spring stage will develop in sufficient abundance to provide rust for infection work later in the season. A bed of young asparagus not ready to cut for market is usually sufficient to provide a lodging place for the spring rust. Artificial inoculation has not been necessary at any time in our breeding fields.

ISOLATION.

After two mated plants have had their progeny tested and have proved their value as a breeding pair they will be dug up and propagated by crown division to secure a stock for breeding. This stock will be isolated and used only to grow seed.

Isolation will be secured by building an insect-proof cage over the field or by planting remote from other fields or wild plants, so that bees will not be able to carry in foreign pollen. The mesh of any cage will have to be small enough to keep out the small wild bees. One of the probable methods will be to grow the plants in the greenhouses in the winter. During the winter of 1910–11 in Washington we have been very successful in setting seed in the greenhouse by hand pollination. In making seed plantations a grower will not be limited to one female plant—any number may be planted with one male. Whenever it is desired to use two males a separate field must be used for each.

PROGENY BED.

In planting seed for a progeny test a uniform piece of good land is necessary. The presence of shade, such as overhanging trees, near-by buildings, etc., should be avoided. The bed should be set so as to be uniformly exposed to the attacks of rust from near-by infection plats. Any marked difference in moisture supply is apt to interfere with the test.

As it is not the intention in the progeny test to grow large plants, the custom at the Concord station has been to plant rather late in May so that all danger of frost and also of the first crop of beetles is past. About 10 feet of seedling row is sufficient for a fair test. Of course, many lots of seed will not plant so much as that, but it is a

useless waste of space to take any more. Rows are first laid out with a line and then made about 2 inches deep with a hoe. The seed is sown by hand and covered with a rake. Skill in planting is acquired by experience, the intention being to drop about six seeds to the foot. A space of 18 inches between rows is ample to allow for passage and cultivation. The two things to judge in the first year are height and rust. The rust on the seedlings is closely correlated with the rust of the plant in future years and height is correlated with size and vigor. The first year progeny test will eventually be the main test of any plant's value in breeding work.

The use of a standard or uniform lot of seedlings as a check on rust infection is desirable, and where accurate results are expected is necessary. In our work up to 1912 we have used Reading Giant. Pedigree stock of good quality alternating with rusty stock will be planted hereafter as a double check.

VALUE OF BREEDING METHODS.

If asparagus growers ever hope to secure reasonably uniform strains of fixed type, the methods of commercial seed production will have to be changed from their present unscientific condition. With few exceptions no attention is now paid to the male parent and little effort is made to get good female plants, the process of seed selection consisting largely of going into a field that has made a good growth and harvesting seed stalks that have well-grown seed.

Mr. Frank Wheeler, of Concord, Mass., has for several years made a practice of selecting the best male and female plants in regard to type, vigor, yield, and rust resistance. These plants have been allowed to grow and bloom during the cutting season. The seed is saved from only those stems of the female plants that bloomed before the general field plants came into flower. These seed plants are the progeny of imported Argenteuil stock and produce a very desirable quality of seedlings.

In the spring of 1908 about 400 one-year plants of this strain were planted in comparison with a similar plat of a strain known locally as "Small" Argenteuil. The yields from these two plats were kept in 1910 and 1911, as shown in Table IV on page 26.

This difference in yield is apparently due to the difference in the strains in which the selection for large stalks by Mr. Wheeler has been an important factor. No apparent difference was noticed in the comparative rust resistance of the two lots, so that rust does not enter as a factor.

If the above striking difference exists through the simple selection methods used by Mr. Wheeler, would not other good farmers be

justified in trying pedigree methods in growing seed? The above-mentioned strain is not pedigreed from either side, the parentage complex including about 20 individuals of each sex. Mr. Wheeler in 1910 and 1911 planted his lots of seed from each female in separate rows. The difference was so striking that in the future pedigree methods will receive more attention.

PROTECTION FROM BEETLES.[1]

One thing to be considered in seed production is the effect of the red or twelve-spotted asparagus beetle (*Crioceris 12-punctatus*), the larval stages of which live in and destroy the asparagus berries. This beetle proved a serious factor in the breeding work last year, and is liable to become worse as time goes on. The first specimens of this beetle found in Concord were discovered in the fall of 1908. The fall of 1910 showed nearly as many as of the ordinary species, *Crioceris asparagi*. Paper bags are not sufficient protection, as in several cases the berries under bags were destroyed. The beetles had either laid their eggs before the plants were bagged or else crawled up inside through the open spaces around the stems. Cages of 16-mesh wire fly screen keep out the red beetle but let in the smaller specimens of the common asparagus beetle. Both kinds may be kept out by the use of 18-mesh wire screen, which will be hereafter used.

PROTECTION OF NONIMMUNE FIELDS.

Spraying methods have been developed by different experiment-station workers in the past that if carefully followed by the grower will keep down the rust. The trouble in applying sprays and the high cost of their efficient application has kept many good growers from using them. Some farmers have gone out of the asparagus business while others have secured the best stock they could find and by careful methods have kept on. The high prices caused by increasing demand and lessening supply has made the profit in asparagus really higher than it was before the rust became known in the country.

It is now certain that by proper pedigree breeding work the whole question of noticeable rust injury in asparagus may be eliminated. At the same time the pedigree breeding work will make uniform and vigorous strains, thus greatly increasing the yield per acre. The elimination of rust as a factor in asparagus growing will render larger yields possible, so that the market price in many locations where rust now prevents adequate returns will fall within reach of the large body of consumers. At present in most regions asparagus is a luxury.

[1] For a full discussion of the two asparagus beetles and of the methods to be used for their control, the reader is referred to Circular 102 of the Bureau of Entomology, U. S. Department of Agriculture.

SUGGESTIONS FOR RUST PREVENTION.

Although the breeding work being carried on with asparagus will eventually lead to the control of rust in commercial plantings, several years must elapse before this result will become effective. Meanwhile, it is necessary to take all measures practicable to prevent the destruction of existing fields of asparagus by the rust. To this end the main factor is to keep the rust away from the fields in summer just as long as possible.

As pointed out by Smith and others, wild asparagus growing around the borders of the fields, along fences, ditches, etc., is one of the worst enemies of the grower. These wild plants act as infection centers and their influence can be easily traced later in the season when the cutting beds have grown up. During the summer of 1910 the writer made an examination of the fields near Concord just at the time the rust was coming on and in every case of infection was able to trace the cause to asparagus plants that had not been cut up to the close of the infection period of the spring rust (Pl. XVIII). When rust was found in a commercial field by following it up to the northwest, the direction from which the prevailing winds come, a young bed, an old neglected bed, or wild asparagus was found in every case and always with the remains of cluster-cup infections. Wild plants wherever found should be dug up and burned. New beds should be planted only at rare intervals of time and then if possible where they will be to windward of a cutting bed. Keep the seedlings out of the cutting bed, at least let none stay in at the time the bed is allowed to grow up after the cutting season. Allow no poor shoots to grow up in the cutting field. In other words, keep down every shoot of asparagus until the middle of June in the latitude of Boston and see that neighboring farmers do the same. In the fall the tops should be removed carefully from 1-year-old beds that are not to be cut the next year. This will in a large measure reduce the liability of infection from this source.

The writer does not recommend the removal of tops from a mature bed in the fall. The ordinary practice in the vicinity of Concord is to leave the bed undisturbed in the fall so that the tops will act as a winter cover and prevent the blowing of soil or snow. In the spring these tops are cut with a disk harrow. Fields in which this treatment had been used have been examined for spring rust after the bed had grown up at the end of the cutting season, but in no case have cluster cups been found. The Massachusetts station has at Concord a 3-acre fertilizer experimental plat on which plants have been infected during 1909, 1910, and 1911 from young beds near by that were not being cut. No cluster cups were found in this 3-acre bed except on plants left for breeding purposes.

SUMMARY.

Puccinia asparagi, the European asparagus rust, was discovered in America in 1896 and in the next six years spread over the asparagus-growing regions of the United States, causing great damage. In the Eastern States no successful remedy was found, although some strains were found to be more resistant than others. Among the resistant varieties were Argenteuil and Palmetto.

The Massachusetts Asparagus Growers' Association, organized in 1906 to obtain a resistant variety by breeding, secured the cooperation of the Massachusetts Agricultural Experiment Station and the United States Department of Agriculture in establishing experimental grounds for this work at Concord.

Previous work on the life history of the disease shows that the rust in all its stages occurs only on asparagus and that the uredo stage is the most injurious. The injury is due to the mechanical and physiological effect on the summer growth which prevents the storage of food supplies for the growth during the next cutting season.

A large number of strains from America and Europe have been collected and tested for rust resistance. No variety proving uniform or satisfactory, breeding work was undertaken to produce a stock that would be commercially immune. Some wild species have been imported from the Old World and one or more hybrids have been produced.

In making selections for rust resistance several acres of the best stock obtainable were used. From the different strains several hundred plants have been selected for pedigree testing after being subjected to attacks of rust.

Rust resistance in asparagus seems to be based upon structural differences. Vigor is not necessarily correlated with resistance.

Breeding work in asparagus is complicated by the fact that the species is diœcious, so that two parents must always be used in seed production. Hand pollination is used for pedigree work.

Progeny tests of select plants have been made each season since 1909. The rust resistance and vigor of these seedlings have determined the value of the breeding parents. The test male A7–83 and the test female B32–39 have given a very superior progeny, which has proved satisfactory as a "commercially immune" type. This progency has been named and plans are under way for its production in quantity.

In carrying out the breeding work, studies have been made of the effect of the weight of seed on seedling vigor, the effect of seedling size on the plant in the field, etc. Correlations between size of plant, yield, rust resistance, etc., have been of value in carrying out the work.

Bud propagation of select breeding parents has been inaugurated to promote more extensive seed production.

Breeders and growers are advised to take up pedigree breeding to produce good strains and to use careful methods in keeping rust out of producing fields.

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